S·A·E JOURNAL

JULY 1930

S. A. E. JOURNAL

Published by the Society of Automotive Engineers, Inc., 29 *W. 39th St., New York*
Cable Address: Autoeng *Telephone:* Longacre 7170

Edward P. Warner, *President* C. B. Whittelsey, Jr., *Treasurer*

Vol. XXVII July, 1930 No. 1

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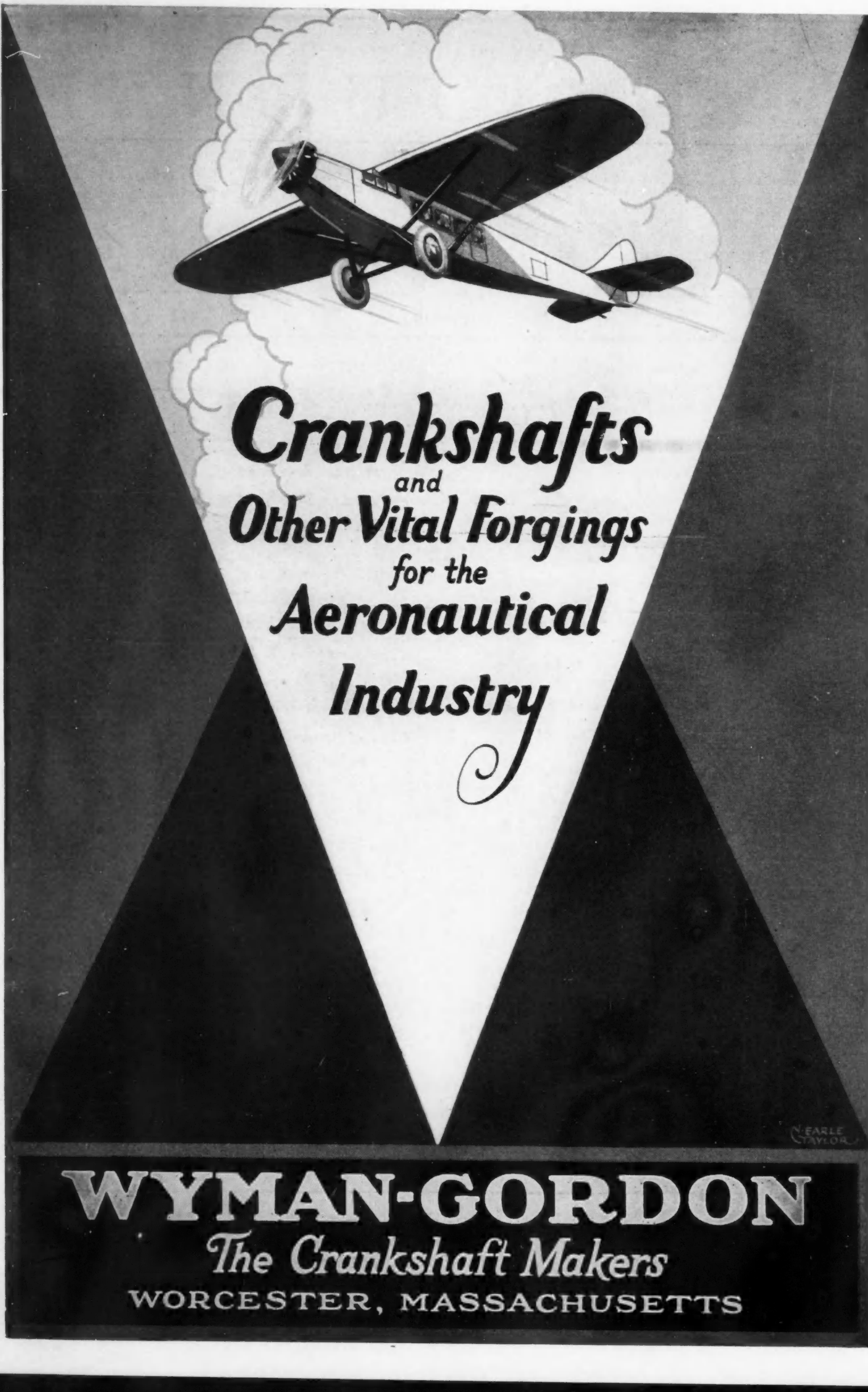
The purpose of meetings of the Society is largely to provide a forum for the presentation of straightforward and frank discussion. Discussion of this kind is encouraged. However, owing to the nature of the Society as an organization, it cannot be responsible for statements or opinions advanced in papers or in discussions at its meetings. The Constitution of the Society has long contained a provision to this effect.


Crankshafts
and
Other Vital Forgings
for the
Aeronautical
Industry
EARLE TAYLOR
WYMAN-GORDON
The Crankshaft Makers
WORCESTER, MASSACHUSETTS

DEDICATED
TO THE MEMORY OF

COKER F. CLARKSON

SECRETARY AND
GENERAL MANAGER
OF THE SOCIETY OF
AUTOMOTIVE ENGINEERS
1910-1930

Coker F. Clarkson

COKER F. CLARKSON

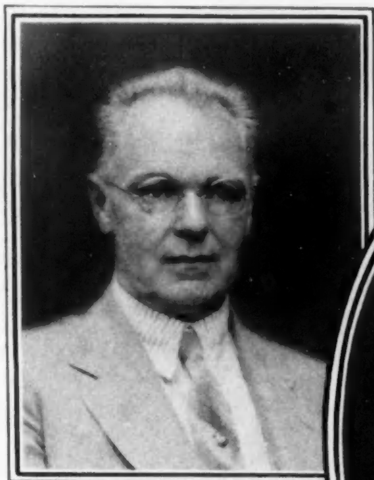
BORN at Des Moines, Iowa, in 1870, Coker Fifield Clarkson entered the State University of Iowa at 14 years of age and was graduated from the Phillips Exeter Academy in 1888. He was graduated from Harvard University with the degree of Bachelor of Arts in 1894 and from the Harvard School of Law two years later, subsequently being admitted to the bar in Philadelphia.

Mr. Clarkson was engaged during 1897 and 1898 in connection with the installation of an underground telephone system in Philadelphia, after which he spent several years in New York City in work on engineering, legal, patent, laboratory and automobile subjects. From 1905 to 1909, he was secretary of the Mechanical Branch of the Association of Licensed Automobile Manufacturers and publicity manager and assistant general manager of the A.L.A.M. He was editor of the Mechanical Branch Bulletins and of the A.L.A.M. weekly digest of current technical literature relating to automobile subjects. He also edited four annual volumes of the Handbook of Gasoline Automobiles, published by the A.L.A.M.

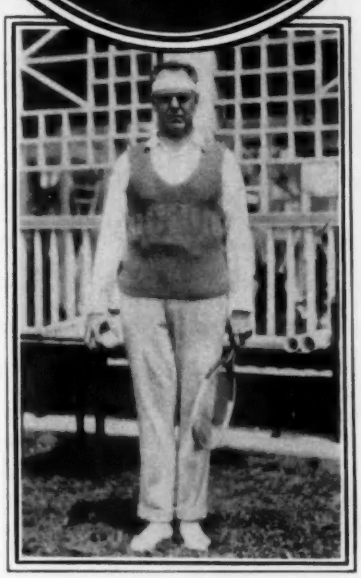
Five years after the organization of the Society of Automobile Engineers in 1905, when the Board of Directors decided that the Society needed a Secretary and General Manager, Mr. Clarkson was appointed to the position, which he held for 20 years. He was the only Secretary and General Manager the Society has had.

Mr. Clarkson's contribution to the service of his Country during the World War was through his association with the Council of National Defense, organized by Howard E. Coffin before the United States became involved in the war and out of which grew the War Industries Board. Mr. Clarkson was appointed a member of the Automotive Products Section of that Board, and was also a member of the International Aircraft Standards Board.

Mr. Clarkson's labors in the S.A.E. were too manifold to be reviewed. He was at all times in close touch with and directed its varied activities, but with a hand that was so light that its guidance was scarcely felt.



A TRIBUTE BY ONE WHO KNEW HIM

An extremely significant and interesting figure of the Country's largest industry, whose work, in terms of economics or of pleasure, affected all of us, has departed the American scene. Coker Fifield Clarkson was a key man, in the true and basic sense, of the great automobile industry, yet his labors were strangely little known to those not closely connected with its affairs. As General Manager of the Society of Automotive Engineers for the last 20 years he, more than any other man, with the possible exception of Howard Coffin, brought into being and made permanent the standardization of parts and methods through which the American automobile business has become the colossal and amazing phenomenon that it is.

Certainly, in the Society, he created what is now accepted as one of the great scientific bodies of the world. It has drawn to its large membership not only the chief engineering and research experts of the automobile industry but those directly concerned of the many other industries allied with automotive production.

A conservative in character but intellectually a liberal, born of the purest American pioneer stock, a son of the late James S. Clarkson, long prominent in National affairs; educated—preparatory school, college and law school—in New England, Clarkson, fascinated by the possibilities of the gasoline automobile, turned abruptly from a probable rich legal career and thus changed the entire current of his life's work. He saw clearly that we were entering upon a new era of transportation which would change the lives of us all. His was a transition as unusual and aperceptive as it proved to be fruitful to a new industry which needed thinkers and men of culture to evolve its laboratory of fact.

In one room in an office building at 41st Street and Broadway in New York City, Clarkson and a small staff, with the backing, financial and moral, of Howard Coffin, always a seer, in war or peace; the late A. L. Riker, and one or two other kindred pioneer spirits, set forth on his scientific Odyssey. He sought to lay a predicate on which to raise a structure wherefrom should radiate mechanical and scientific understanding for the benefit of an industry struggling for birth so that it might transform itself into the business Titan that later took form.

The solution was standardization. Many mouthed the term in the early days of the automobile but few knew what it meant. It is a lumbering word which holds a world

of romance for a mechanistic age. Its application and ever-ramifying growth, made possible by the most faithful and tireless co-operative research under the quiet guiding hand of Clarkson, working at his standing desk in the Engineering Societies Building in New York City, moving here and there to the meetings of the Society over the Country, is responsible in very great measure for the automobile industry as we now know it—for its speed and quantity of production, due largely to the simplification of parts and practices synonymous with far-seeing and sane standardization.

Today the many standards of the Society of Automotive Engineers are accepted all over the world; even by our own ultra-conservative Bureau of Standards. They have become the textbook of modern motor-car production.

To cite only one instance of the standardization work, it made possible one of the most dramatic and useful achievements of the World War, the building of the Liberty, or heavy-duty Class B, motor-truck. Drawings for this truck, called for by the War Department to meet insistent and critical war transportation needs, were begun on September 1, 1917. Fifty engineers selected by the Society, working day and night, evolved the design. Incredible though it may seem, two completed trucks started on trial trips from Lima, Ohio, and Rochester, N. Y., on October 10, 1917. They rolled into the City of Washington on October 14, on time to the minute, to be greeted by the War President and a group of distinguished officials. The trick was done in just 40 days. Here was standardization in action, applied this time to a National emergency.

When we entered the World War, Clarkson's self-effacing work began to receive partial recognition. He was drafted for service on three outstanding Federal war bodies: the Council of National Defense, the War Industries Board and the International Aircraft Standards Board.

Deeply studious, with a prodigious capacity for silent work; possessing great outward phlegm fully matched by an extraordinarily keen inner sensitiveness; inflexible in principle; filled with an inherent sense of justice which all near to him recognized; incapable of affectation or self-italicis; saturated with the sense of impersonal labor and purpose which alone makes the true executive, Clarkson drew to him the admiration and affection of the varied types of the huge new industry to whose imperative problems he addressed himself incessantly during the most vital period of our times. Upon his field of endeavor he left an impress which will be more accurately valued as the titanic processes of American industry unfold themselves to the succeeding generation.

IN THE WORDS OF HIS FRIENDS

In the following pages are included a small portion of those reflections on the life and work of Coker F. Clarkson which, to the editors, seem best to reflect the character of the man as seen through the eyes of his friends. Such expressions, astonishingly voluminous, here so much abridged with great reluctance, leave no doubt of the impress of the man, the breadth of his interests, the richness of his associations, the pain of his loss.

COKER F. CLARKSON derived much from his immediate ancestors. His grandfather, Coker Fifield Clarkson, earlier than 1860, brought from Brookville, Ind., to Hardin County, Iowa, a vigorous body, two vigorous sons and their mother. All had been influenced by Henry Clay and succeeding Whig and anti-slavery leaders.

In Iowa the elder Clarkson took immediate leadership and, with his sons, about 1870, acquired the *Iowa State Register*, a Republican newspaper published in Des Moines. The elder Clarkson became an authority in agricultural reform; one son, the manager; and the other son, the editor.

Of the editor, James S. Clarkson, and his brilliant wife, Anna Howell Clarkson, Coker F. Clarkson, Jr., was born. Distinguished American statesmen and business men, including James G. Blaine, Murat Halstead and Benjamin Harrison, made the home of James S. Clarkson theirs also. So Coker, Jr., early became familiar with achievement. His father, who became Assistant Postmaster General in the Harrison administration, disposed of his interest in the *Iowa State Register* and removed to New York City, where his business associations provided a contact through which Coker, Jr., applied his own remarkable capabilities.

EDGAR H. HARLAN, *Curator*
Iowa State Historical Society

WE beg to convey our deepest sympathy on behalf of the French Society of Automotive Engineers.

EUGÈNE MATTHIEU *and* HENRI PERROT
Société des Ingénieurs de l'Automobile

THE motor industry, and certainly the engineering side of it, will not be the same without the courteous, smiling, helpful Coker F. Clarkson. He was considered just as high among the executives of our organization as he was among the members of the Society of Automotive Engineers. He contributed much to the advancement of the industry of which he was a very important part, and his passing takes a citizen and a cooperative worker of the kind that makes American business standards what they are.

ALFRED REEVES, *General Manager*
National Automobile Chamber of Commerce

WE were deeply grieved to learn of the sudden death of Mr. Clarkson, to whom the automotive industry and your Society owe so much. The high standing of the Society of Automotive Engineers and its many splendid accomplishments are in themselves one of the highest tributes that can be paid to his exceptional ability. On behalf of the American Society for Testing Materials I wish to extend to the officers and members of your Society our sincere sympathy in the great loss that you have sustained in Mr. Clarkson's death.

To this may I add a brief expression of my personal sympathy. My relations with Mr. Clarkson as a fellow executive in technical society work were always most cordial and pleasant and I am deeply grieved at his passing.

C. L. WARWICK, *Secretary-Treasurer*
American Society for Testing Materials

UPON reviewing our associations with some men, it is interesting to find that our minds hold only pleasant recollections. Such is the case now as I look back upon my years of acquaintanceship with Coker—an acquaintanceship which developed into such high regard through the warmth of his personality. Under the surface of his seriousness there lay a wealth of humanness—a humanness which broadened with his years as the result of his deep philosophy of life. I think nothing appeals to me more at this moment as an evidence of his humanness than the tributes which are being paid to his memory by the large number of his friends in all walks of life.

M. L. HEMINWAY, *Managing Director*
Motor and Equipment Association

IT was a very great shock to receive your cablegram telling me that Brother Clarkson had passed away. It is a tragic coincidence that his death should have occurred just at the time that the Society is celebrating its 25th Anniversary, and I hope you will accept my sincere sympathy and convey the same to the members of your Society.

BASIL H. JOY, *Secretary*
The Institution of Automobile Engineers

IN the passing on of Coker F. Clarkson, for many years the efficient Secretary of the Society of Automotive Engineers, the Society, the automobile and airplane industries, and the entire Country have sustained a serious and distinct loss.

Mr. Clarkson was far more than an ordinary man. His position all these years as Secretary of the Society was not simply to fill the place satisfactorily. He had vision, and the man who has real and true vision of the possibilities and great achievements which any given invention, device or principle can accomplish to promote human endeavors, to increase efficiency, to increase the employment, comfort, pleasure and wealth of our Country—any man who really has vision like this, and then has the capacity and the "know-how" to get the masses to see and help him to transform his vision into a living, vital, moving, permanent reality—is a rare man indeed and a benefactor of the human race. Such a man was Coker Clarkson.

My memory will ever cherish many most happy recollections of the constant suggestions, the helpfulness, which Mr. Clarkson was ever ready to give me during my term as President in 1914 and to everyone interested in the great work of this most useful organization.

HENRY M. LELAND

WORDS are weak things with which to pay tribute to Coker Clarkson. He has been for 20 years one of the most constructive figures in American industry. His remarkable qualities of leadership and his quick efficiency, as well as his singular and unselfish devotion to his life's great work, have made for him a lasting place in the hearts of all of us whose privilege it has been to know him. He has had our admiration for his accomplishments, our respect for his ideals and our love for him as a friend. The structure he has builded will live on in the useful fulfillment of his vision, and his memory will remain an inspiration to us always.

HOWARD E. COFFIN

COKER CLARKSON had that rare capacity of sitting back behind the scenes and not pushing himself forward which made for success in the organization with which he was connected.

It was always a very great pleasure to be associated with him officially, because his integrity and loyalty could always be depended upon. Mr. Clarkson's successor, will have a very large pair of shoes to fill.

H. W. ALDEN

I FIND myself totally unable to grasp the fact that a man whom I have been so proud to consider as my friend has passed away in what seems to be so sudden a manner, in spite of the length of the illness which he has suffered.

While my fears for his ultimate recovery have been with me constantly, I had more or less set them into subjection to the hope that he would recover his health and once more take his place in the activities of the Society to which he had devoted so many years of his life with such excellent results.

Having had the honor to hold the responsibilities which are President Warner's this year, I can in a degree appreciate the loss which you have suffered, and offer my sincere sympathy.

B. B. BACHMAN

It is a supreme tribute to our dear friend, Coker Clarkson, that every member of the Society and the industry feels a deep sense of personal loss in his passing. He was the one man in the industry to whom friends and opponents alike could confide their innermost thoughts with confidence that he would keep and use them without the violation of the trust and without favor. This stamps him as a master of the art of living—the greatest and finest of all arts.

We have beheld the most nearly perfect man. He was above all human, tolerant, sympathetic, loyal, faithful, broad in vision and interest, long-suffering and patient, tender in wisdom, and a true advocate of all that was fine in real men. His was the perfect sense of the fitness and the proprieties of all things. He seemed to have the most complete sense of perfection. His sense of absolute justice was his outstanding quality. He was eager to accept and quick to act on constructive criticism.

We never will know a more unselfish or guileless soul. Living and enmeshed in the very heart of this mechanical and materialistic age, he refutes every criticism of our civilization by the richness of his human and spiritual qualities. His life and manner of living are best expressed by an ancient philosophical saying: "Civilization is the sum of all those intricacies whereby every man is granted the opportunity to maintain his dignity and self-respect." It was this just respect for the feelings and opinion of others that made possible his great achievement in managing men, forming events, and welding innumerable men together in bonds of friendship.

A student at Harvard, under William James, he ever after was a tireless reader of philosophy and psychology, which he practiced with masterful skill in the great laboratory of life. He studied political economy with Taussig and was henceforth a constant explorer for the best among modern economists. Dewey was one of his favorite modern philosophers. He was profoundly impressed by Martin's, "The Meaning of a Liberal Education." From "The Tragic Sense of Life," by the modern Spanish philosopher, Unamano, we get a glimpse of our friend in this marked passage: "This longing or hunger for divinity begets hope, hope begets faith, and faith and hope beget charity. Of this divine longing is born our sense of beauty, of finality, of goodness."

Nothing better reflects the inner man than these quotations:

> "The superior man is dignified and does not wrangle; social, but not a partisan. He does not promote a man because of his words, but he does not put aside words because of the man."

> "In style all that is required is that it convey the meaning."

> "Learning undigested by thought is labor lost. Thought unassisted by learning is perilous."

The saying, "Talent is nurtured in solitude, but character is formed in the whirlpool of conflict," explains to us how it was that there came and lived among us so great a man. While others were enjoying the amenities of easy living, he was searching in solitude for the meaning of life. The secret of his many achievements was that he never ceased to be a student. The books he read were profusely marked and underlined, and the margins covered with his keen reactions. He gathered clippings constantly and filled volumes with notes on every subject.

His letters were the finest expressions of his genius; friendly, warm, sparkling and filled with wisdom, and, emanating from a fine mind and an unblemished soul, they were the priceless jewels of friendship.

We find in his library the indisputable evidence of his true nature. Aside from the many annotated volumes, which tell the remarkable story of his scientific philosophy, we find four volumes by different authorities on the Life of Christ; volumes on the Life of the Prophets; Bibles marked in his own handwriting with that care and thoroughness which were so characteristic; and religious textbooks marked with meditation. "Faith is the creative power in man." The story of his last years and days, as outlined by his hand in these books, tell of longing for and a profound faith in his Maker, and in his last days a deep sense of the life to come.

We shall never know a more loving, finer and truer friend. We shall miss him, and yet his spirit shall live with us forever.

HARRY LEVAN HORNING

I KNEW and admired Coker Clarkson for his geniality under all conditions and for his remarkable quality of instant comprehension of all that was going on about him. He never tired through a long and tedious meeting and was ever ready and willing to lend a helping hand in the solution of any problem. I am proud to have been numbered among his friends and associates.

HOWARD C. MARMON

LOOKING back on my association with Coker in the management of the Society, I am tremendously impressed with his remarkable executive ability. To my mind, he was an unusual example of the finest modern type of business leader.

He had a complete knowledge of all the details of the work under his direction and worked in the closest cooperation with his various subordinates. The inspiring example of his industry and clear thinking obtained a remarkable degree of efficiency from his associates, both among the office personnel and the elected personnel of the Society management.

The entire business of the Society, under his direction, was handled in a perfectly orderly manner, presenting all important information in the simplest and clearest possible form and yet with a complete flexibility, a rare combination. His management of *The Journal* was an exceptional combination of editorial ability and business judgment.

Very few of the highest executives in the automotive industry realized that he controlled the expenditure of a budget of over a quarter million dollars, a considerable part of which was earned under his own direction.

His charming personality and the modesty that led him to give the utmost prominence to the work of the elected offices of the Society prevented many from realizing his unusual qualities of leadership.

HENRY M. CRANE

PERMIT me to join with you and the members of the Society and the Metropolitan Section in mourning the loss of our great leader, Coker F. Clarkson.

THOMAS J. FAY

IN our work together, I always felt extremely grateful to Coker Clarkson for the very fine assistance which he was to me as a member of the Council and as a President of the S.A.E.

To me, Coker Clarkson has always meant the S.A.E. His very diplomatic and efficient work, which I noted particularly when working with him, fitted him preeminently for his job.

I feel that Coker Clarkson has probably done as much as all others combined to further the success of the Society.

J. G. VINCENT

IN Coker Clarkson was exemplified the spirit of the Society of Automotive Engineers: open and fair minded, unselfish and tirelessly working for the betterment of the industry.

His was a clear, analytical mind, and in the face of discouraging circumstances he was at his best.

What better tribute can be paid than that he was respected and admired by all and loved by those who were so fortunate as to number him among their friends?

As President of the Society in 1917, it was my privilege and great pleasure to be very closely associated with him. We were together constantly for weeks while opening and organizing the Society offices at Washington, and I have rarely experienced such spontaneous and thorough cooperation and understanding, especially under such trying conditions. There is no doubt that Clarkson's efforts had a distinct influence on the early contacts made with the Government, without which the remarkable coordination following might have been experienced in a lesser degree.

The Society has lost one of its leaders, so able that, if the work, as in the past, is to be advanced with an ever-increasing usefulness, the members must lend additional effort to its many activities.

GEORGE W. DUNHAM

It is men like Mr. Clarkson that make life worth living and make life worth while. The world is better for his having been in it.

E. S. LAND
Captain (C.C.) U.S.N.

ANY small contribution made by any member co-operating in the administrative work of the Society of Automotive Engineers has always been repaid many times by the pleasure and education coming from contacts with men similarly engaged. This is true of any technical society. Members attempting to serve the S.A.E. have had an unusual pleasure and privilege in the opportunity, not only to work with Coker Clarkson, but also to realize the real worth of the man and to value him as a friend.

Coker Clarkson's policy as General Manager of our Society was always to place the responsibility for all decisions on the Council. The pertinent facts were always ready, and on questions of major importance the Council was always notified in time so that individual members could make an independent investigation if it seemed desirable. If some group of members were particularly desirous of accomplishing any change, they could always depend upon his bringing their viewpoint before the Council in a most adequate manner. If any mistakes were made, they were made by the Council. Coker was so quietly efficient in carrying through this policy that it must have taken others, as it did myself, some little time on the Council to realize how completely his work was determining the success which the Society enjoyed.

He was thoroughly modest in bringing business before the Society. His assistants were given every chance to show the results of their own good work, and a smoothly working staff was developed and maintained.

No one can really replace him in the Society, but the organization is there, and the way for his successor has been made as smooth as Coker would have planned it if given an opportunity. The membership have only to carry on to provide the memorial which he deserves, and to which he gave the best years of his life—a successful Society.

J. H. HUNT

To those of us who not only have known Coker F. Clarkson for years but also during the last active years of his life's work, the passing on of his sublime spirit leaves us with a vacancy unfillable. With all his application to his work, there flowed the gentlemanly interest and love and attention for his co-workers and friends which removed the toils and vexations of business worries and lightened the tasks ahead. Coker was no ordinary mortal; he had and was of the old heroic strain—a leader, a chancellor, so to speak, like Bismarck—who guided the affairs of the Society through the administrations of the many Presidents and Councilors and kept the ship on an even keel; strong, sure and respected.

Memory of him is inspiring and we now have a keener appreciation of his character and work, which we will endeavor to carry on to his honor and glory.

W. R. STRICKLAND

WHEN I learned of the passing of Coker Clarkson, I, like most of his friends, was so shocked it was indeed difficult to give any coherent expression in paying adequate tribute to this remarkable man.

Following many years of close association with him, I would say that this master engineering and business executive was a most outstanding character. He not only managed the affairs of the engineering corporation, with its numerous committees and many meetings, but he also was editor-in-chief of a great engineering publication corporation, for that is what the S.A.E. has now become. Under his extraordinary genius we have steadily progressed through prosperity and panic.

I have observed him at work and at play, in repose and in action. One of his traits which I greatly admired was the way he would slip away from the office and retire to the Harvard Club, where he could plan and concentrate without interruption, beyond the reach of the telephone. I had many conferences with him in this club. And he knew how to play as well as to work. I remember at one time bragging a little about having lighted the first tennis court in America for night tennis. Quick as a flash he said, "Well, let's play," and, while he did not beat me, he took a keen delight in squaring matters a little later by beating me at pool in my Indianapolis home. At play he seemed to completely forget his business worries.

On the train from New York City to Scarborough it seemed to me that half the commuters knew him,

and you could tell by the way they hailed him that he was well liked.

His calm enthusiasm and sober judgment inspired great confidence in his associates; never hectic, always good natured, with a twinkle in his eye even in the midst of a hot Council session. His was a personality to be envied. Would that more of us could emulate this remarkable man.

THOMAS J. LITLE, JR.

WHEN I think of Coker Clarkson my first idea is always that of seeing him with his coat off, wading through an enormous amount of correspondence and reports, as I have so often seen him, either at headquarters or in his hotel room at the many meetings of the Society.

While I had met Coker before, I did not become closely acquainted with him until the S.A.E. European trip in 1911, when we spent considerable time together.

In cleaning out a lot of old papers several days ago, I ran across the passenger list of the *Olympic*, which was the boat a number of us came back on from that trip, and by chance I opened it at Coker F. Clarkson's name. There were quite a number of us on that trip among them being: Howard E. Coffin, Arthur J. Slade, C. S. Mott, B. B. Bachman, Fred S. Duesenberg and A. B. Cumner; Coker being well informed, proved to be an ideal companion for a trip of that kind.

During the many years since then, he never seemed to slacken up in the least in the great amount of work he did, and it was only occasionally that he could be gotten away to play. I had a great deal of pleasure from being with him at different times, for, although the affairs of the Society were ever present with him, he was a very interesting talker, and all those who knew and came in contact with him will miss him greatly.

WILLIAM G. WALL

COKER F. CLARKSON had two dominating characteristics in his business life: his sincere conscientiousness to detail and his untiring determination to obtain the truth on any and all matters. It was not uncommon for him to revise an important telegram several times before dispatching it, and on one occasion during the war period a cablegram going to London was not only revised several times but referred to several persons for comment.

This attention to detail and pursuit after truth were unquestionably due to the basic knowledge he possessed on engineering and patent affairs, plus the consciousness that details and facts are of prime importance in both of these.

Coker never strayed from either of these cardinal considerations and, while the former imposed an unusually heavy load to carry, he was always ready to draw heavily on the 24 hours of the day so that he might give that attention to detail which he considered necessary.

DAVID BEECROFT

COKER CLARKSON was much more than the Manager of the S.A.E. He was more, even, than the representative of its spirit and the friend of all its members. He was the absolute embodiment of the organization.

The Society has grown up under his care. He had not been wrapped up in it to the extent of being prevented from having personal interest in a wide variety of matters, but it was never really absent from his thoughts. From the most recondite of its technical sessions to the Summer Meeting tennis tournaments, in which he was for years a habitual winner, he cherished and supported its every activity.

The word "personality" forces itself into any reflection on his work. An organization may have all that can be dreamed of efficiency and still be lifeless. It takes an individual to give it a soul. We who have been active in the S.A.E. are proud to consider it as outstanding among technical societies. If our pride be justified, it is because the headquarters in New York City represented itself to the membership at large, not as a collection of filing cabinets and dictaphones, but as Coker Clarkson and a little group of loyal and enthusiastic collaborators. Scores if not hundreds of us knew him as Coker, and he wanted no more stilted or "dignified" title. Of the 7000 members of the Society, every

one who had the privilege of coming in contact with the work at headquarters was his personal friend, and everyone has suffered a personal loss.

EDWARD P. WARNER
President

Coker F. Clarkson, a man among men, untiring in his efforts, unequalled in his fairness and patience in dealing with others, and yet so self-effacing in all his work that his true greatness will not be realized for years to come.

It has indeed been a privilege, which will often be remembered in later years, to have known him, to have had the pleasure of working with him, and to have had the honor to consider him as a friend.

C. B. WHITTELSEY, JR.
Assistant to the General Manager

Coker F. Clarkson's reserve, which forbade familiarity, and his modesty, diffidently waving aside personal tribute, restrains praise or appraisal of him now. While I, in common with many others, owe him an immeasurable debt for the inspiration of his service as counselor, guide and mentor, it is a task quite impossible to reduce to words the lasting impressions gained through 18 years of increasingly close personal association culminating through the last several years in daily contact. Still, a sense of loss cries for expression, and the conviction that in furthering, in dynamic loyalty to him, the growth of the Society, his philosophy must be applied; a philosophy so broad and so profound as to require for its understanding the combined contributions of all to whom it was happily given to glimpse any part of it.

Coker Clarkson exemplified the enunciation of whosoever shall lose his life, the same shall save it.

In forming his judgments, he submerged his own personality. Unassuming and unopinionated, he was not only receptive of the ideas of others, but actively sought their council. With a high sensitivity of perception and feeling, with the brilliant illumination afforded by untarnished honesty of purpose, with vision unobstructed by prepossession or prejudice, he saw clearly into men; he pierced through the confusing intricacies of events to discern their true significance and trend.

In guiding the destinies of the S.A.E., his methods resembled the slow, irresistible and innately sound processes of nature. He never thwarted an honestly conceived plan of a co-worker or assistant, but so shaped it as to make it fit into a harmonious whole; and by encouragement and suggestion so tactful as to be almost imperceptible enabled its originator to bring it to a fruition more successful and vital than he had dreamed of. Each successive administration of the Society has been stamped with the individuality of its President and Council; all have been combined into a unified pattern by him who for 20 years consecrated and finally sacrificed his life to the task of master weaver. A concrete, indicative example of his ability to evoke and emphasize the ability of others may be found in his editorial work. To authors would be continually revealed, by his blue-penciled corrections, even in their own work, not only more lucid and graceful expressions, but greater depth and clarity of idea. In seeking to persuade, he appealed always to reason, never to the emotions of fear, hate or pride.

Although he awaited the natural developments of issues with enduring patience and undisturbed equanimity, he did not lack the resolution of idealism in diverting from them any harmful ingredient. Progressive as evolution itself, he was always ready to shuck off the old as soon as the new had manifested its merits and its ability to withstand unfavorable comment and criticism. His plans, when they came to maturity, would bear witness to his complete mastery of detail, because his true artist's mind called for perfection to the minutest particular; he was an artist who worked in men and events as his media, and the S.A.E. is his creation, not a static thing of marble or oil and canvas, but his living monument that will continue to derive its growth from his undying inspiration.

Modest, wise, sympathetic, indefatigable, courageous, serious of purpose and cheerful of demeanor; my beloved friend,

"He was a man, take him all in all
I shall not look upon his like again."

C. B. VEAL
Research Manager

A GREAT knowledge and understanding of men and affairs and a quiet—almost retiring—way of meeting them; a wonderful mentality and a capacity for accomplishment as personified in Coker F. Clarkson, have in his passing to a new life, left a void in this that no other man can fill. His friendship and helpful leadership have left an indelible impression on all who knew him and on a great industry.

ROBERT S. BURNETT
Manager Standards Department

WHY need we memorials of a friend and co-worker whose personal impress and life are so thoroughly stamped on all that is automotive as to be an integral part of it?

I first met Coker Clarkson in 1904 when the industry was still in its swaddling clothes. He was the same sincere, earnest, far-seeing Coker then as he is now—and will ever be in the hearts and minds of those who knew him well.

A true American, reared in the West, educated in the East, with a full sympathy for mankind and its problems, he became, by virtue of his social and engineering contacts, a citizen of the World.

Locally and internationally the loss of his physical companionship will be mourned, but no one who knew him intimately can say he has left in spirit. Coker Clarkson is, indeed, an Honorary Member of the Society!

FAY LEONE FAUROTE
Publicity Manager, S.A.E.

"C.F.," as he was best known among members of the office staff of the Society, was a highly appreciated employer and associate and as such his loss is sincerely deplored.

My personal acquaintance with him extends back to the days when he was manager of the Mechanical Branch of the A.L.A.M., although it was merely casual until I joined the editorial staff of the S.A.E. *Journal* more than five years ago. During these five years I found him a man for whom it was a delight to work. Never dictatorial or fault-finding, uniformly courteous and friendly, he was always ready to listen patiently to the presentation of a problem or a question of policy.

After hearing a subordinate through, asking a leading question now and then, and making an occasional statement that threw additional light on the subject, he would be likely to say, in his deliberate drawling way, "Well, I would do thus and so," or "Well, what do you think?" and dismiss the subject with, "Well, use your own judgment."

He was a far-sighted and clear thinker, conservative and extraordinarily careful, meticulous in the matter of accuracy and literary quality in all printed matter, and induced conscientious persistent work from all members of the staff by the example he himself set.

Work of the Society always took precedence with him. At National meetings, when he was to sit at the speakers' table at a banquet, he would often be missing and would finally be found in his hotel room working over a Council meeting report for *The Journal*.

He worked into the early hours of the mornings, and to avoid numerous interruptions that would inevitably have occurred at the office, spent his forenoons at the Harvard Club in reading and considering office papers.

Perhaps such unremitting toil served to weaken his resistance; he had always kept in good physical condition by vigorous athletics, including tennis, squash, golf and the like.

H. W. PERRY
Publication Department

To know Coker Clarkson was to love him and respect him. His sincerity, fairness and genuineness endeared him to us all, and his memory will always inspire us to carry on and give the best that is in us, as he always did. I deeply regret the loss of a real friend and counselor.

JUDY A. MCCORMICK

THE passing of Coker Clarkson has removed from our midst a man who commanded from men a very rare thing—affection. His unassuming influence, while very often unexpressed, was nevertheless felt

in every phase of the activities with which he was connected.

Personally, I feel that the nearly four years of association with him which it has been my privilege to enjoy, has been and will be more valuable to me in my business career than any other single influence.

A. J. UNDERWOOD
Standards Department

COKER CLARKSON was the great sustaining influence responsible for the growth and accomplishments of the Society. The annual change in Officers and Council made it essential that the continuing influence of Coker Clarkson should guide the way for the Society. He brought to the office a dignity that was democratic. He possessed an uncommon sense of humor, congeniality and diplomacy which smoothed the ruffled waters in the many controversial matters which are bound to arise in the administration of the Society's affairs.

Coker could always be depended upon to bring the most thorough analysis to bear upon all problems before expressing his opinions. He was a firm believer in meditation before action. He was not generally appreciated for his qualities of leadership because of his genuine modesty regarding his own achievements and suppression of the fact that any views he expressed were his personal ones.

Coker Clarkson was an outstanding journalist, bringing to *The Journal* a standard of grammatical expression, style and accuracy which placed it in the top rank of engineering publications. Many a poor engineering paper has grown under his blue pencil to an engineering thesis of outstanding merit. The members of his staff appreciated his insistence on perfection in all that was undertaken by that able organization. No man can ever be more unselfish in his arduous labors for the advancement of an institution. The S.A.E. and its accomplishments serve adequately as Coker Clarkson's memorial. I personally feel deeply the loss of the most inspiring personality and friend under whose direction it has ever been my privilege to work.

L. CLAYTON HILL, *Chairman*
Detroit Section

I LIKE to think of Coker Clarkson in his office, quietly executing his many duties. Just before *The Journal* went to press, for example, Coker and his blue pencil could be found, working out the mistakes and inaccuracies in the page proofs. Those who have labored on *The Journal* have learned to respect that blue pencil as a very exacting monitor.

Often, in the midst of a weighty discussion, particularly when some member of the group was taking himself too seriously, a trace of a smile would appear on Coker's face, then a broad grin, and the signals were set for a lively anecdote that would clear the air and restore a proper perspective.

Coker would lay aside an urgent piece of work in order to greet a caller, a stranger perhaps, who had come with a real mission. With utmost patience, understanding and sympathy the visitor would be heard. Invariably he would leave with a feeling that he had met a real friend, a man who was ready to assist in carrying the burdens of others.

Never have I known a man more just or honest, more genuine or steadfast, more kind or sympathetic than Coker. In him the cardinal virtues, so generously intermingled, found expression in the perfect harmony of a well-ordered life.

Coker Clarkson built the Society of Automotive Engineers from the elements of his leadership, self-sacrifice and devotion. What a magnificent living memorial he has left to us who mourn his loss!

JOHN WARNER, *Chairman*
Meeting Committee

WE of the Canadian Section are much distressed by the sad news of Mr. Clarkson's death. It will be a big loss to the Society, as, while we have in the Society a great many men of ability, it is going to be extremely hard to find a man who has the ability and at the same time has the peculiar nature that has characterized Coker's daily contact, not only with the business of the Society, but with the members. Personally, I feel sometimes that the Almighty makes mistakes in picking out those whom He takes from us, but maybe He needs them Himself.

R. H. COMBS, *Chairman*
Canadian Section

S. A. E. JOURNAL

Vol. XXVII July, 1930 No. 1

National Aeronautic Meeting in August

Six Technical Sessions To Be Held in Chicago at Three-Day Meeting in Conjunction with National Air Races

CHICAGO, which this year is to be the scene of the National Air Races, will also be the locale of a National Aeronautic Meeting of the Society. The Air Races each year are drawing executives and engineers in increased numbers from all aircraft and aircraft-engine companies and also from allied industries.

Coincident with the increase in aeronautic activities a great number of engineering problems have arisen that must be solved if progress is to be maintained and furthered. As they appear these problems are being presented at the National Aeronautic Engineering Meetings of the Society so that their discussion in an open forum by engineers and authorities may assist in the development of the art or in some satisfactory solution of the many difficulties now present.

Six sessions, one a banquet, will be held mornings and evenings on Aug. 26, 27 and 28, at the Palmer House, one of the official hotels designated by the National Air Race Association.

Thursday evening, Aug. 28, is to be devoted to an Aircraft Banquet, presided over by William B. Stout as Toastmaster. While the speaker of the evening has not yet been definitely determined, a National figure in the aeronautic field will address those present on some timely topic.

Symposiums on Spinning and Fuels

One of the sessions will be conducted as a Symposium on Spinning, at which all phases of spins, their causes and prevention, will be presented by such well-known engineers as Paul E. Hovgard, of the Keystone Aircraft Corp.; Harry A. Sutton, of the Aviation Corp.; Garland P. Peed, Jr., well-known test pilot; Temple Joyce, of the Berliner-Joyce Aircraft Corp.; and Fred E. Weick, of the National Advisory Committee for Aeronautics.

Similarly, a session will be devoted to the discussion of the essential characteristics of aircraft fuels, which subject is today a moot question on which authorities differ. While the final program for this particular session has not been entirely determined, the subject will be treated by representatives of air-transport lines, engine manufacturers and fuel producers. It is anticipated that from this discussion will come some information that will enable some definite steps to be taken to assure progress being made or an agreement of opinions reached between producers and users.

Engines and Flight Research

Aircraft engines will be discussed in two papers from the angles of cost and design, particularly as compared with automobile powerplants. J. W. Crowley, Jr., of the National Advisory Committee for Aeronautics, will present a paper on Flight Research, which will give the results of the work done by this organization in recent months. The remainder of the program, which cannot be announced at this time, will treat aerodynamic matters and problems of structural design.

The National Air Races are to be held at the Curtiss-Wright-Reynolds Field in Chicago from Aug. 23 to Sept. 1. They will be supplemented by various cross-country derbies from different points in the United States. The races themselves will bring together the cream of the racing pilots—civilian, Army, Navy, Marine and National Guard—and should provide a series of events larger than any heretofore attempted.

As in the last two years, Clifford W. Henderson will be managing director of the races, and Major R. W. Schroeder will be Contest Committee chairman in actual charge of racing events.

Production-Meeting Plans

Three Technical Sessions, Visits to Detroit Plants and Production Dinner Scheduled

PLANS are now being shaped for the National Production Meeting to be held in Detroit on Oct. 7 and 8. There are to be three technical sessions, one of which is to be devoted to the economics of production. In addition, one or more inspection visits are to be made to local manufacturing plants, and the meeting will close with a Production Dinner, to be held the evening of Oct. 8 at the Book-Cadillac Hotel, where the sessions also will be held.

The program and management of the dinner are being arranged for by the Detroit Section under the direction of Chairman Phil Kent.

Speakers and papers scheduled for two of the technical sessions are as follows:

R. L. Templin, of the Aluminum Co. of America, will speak on New Developments in Machining Aluminum and Its Alloys.

W. H. McCoy, of the General Motors Corp. Research Laboratories, will deliver a paper on The Use of Cemented Tungsten-Carbide Tools.

J. C. Hough, of the Mathews Conveyor Co., is to give a paper discussing the Design Elements and Economic Conditions of Material-Handling Systems from the User's Point of View.

E. J. Bryant, of the Greenfield Tap & Die Corp., will present a paper on Wear Allowances and Tolerances on Gages.

At the Economics Session, Paul N. Lehoczky, of the Ohio State University, is to give a paper on Economic Production Lots, and C. B. Jones, of the Detroit School of Applied Science,

will present one entitled, The Tool Engineer's Place in Mass Production.

The meeting program is being arranged through the efforts of J. Geschelin, of the Chilton Class Journal Co., who is Chairman of the Meetings Committee of the Production Activity Committee, of which latter Committee John Younger, of Ohio State University, is Chairman.

Meetings Committee Plans

Arrangements for Productions, Transportation and Aircraft Meetings—Activities to Suggest Annual Meeting Topics

THE Meetings Committee met at dinner on the evening of Tuesday, May 27, the third day of the Summer Meeting, with Chairman John Warner presiding. In addition to Chairman Warner the following were present: President Edward P. Warner, C. S. Bruce, P. W. Eells, F. C. Horner, P. J. Kent, W. C. Keys, A. J. Poole, N. G. Shidle, J. P. Stewart, and, from the Society staff, R. S. Burnett, A. J. Underwood, C. B. Veal and C. B. Whittelsey, Jr.

Several proposals were made regarding the site of the 1931 Summer Meeting, followed by lively discussion. It was agreed, however, that the Committee would study the matter further before offering a recommendation to the Council.

The Committee voted to recommend to the Council that the 1931 Annual Meeting be scheduled for the Book-Cadillac Hotel, Detroit, during the week of the Detroit Automobile Show.

Summer and Fall Meetings

Chairman Warner called upon Mr. Burnett, the staff contact-man for the Transportation and Maintenance, the Motorcoach and Motor-Truck, and the Production Activities, to outline the meetings plans for those Activities. Mr. Burnett reported that the National Production Meeting will be held in Detroit, Oct. 7 and 8, and that the program for the meeting is rapidly assuming definite shape; also that the Transportation and Maintenance Activity, together with the Motorcoach and Motor-Truck Activity, will hold a National Transportation Meeting in Pittsburgh, Oct. 22 to 24, the program for which is almost complete.

The Aircraft and the Aircraft-Engine Activities, Mr. Underwood reported, will cooperate in holding a National Aeronautic Meeting in Chicago, Aug. 26 to 28, during the week of the National Air Races, jointly with the Aeronautical Chamber of Commerce of America. An Aeronautic Meeting will also be held on the Pacific Coast in connection with the West Coast Air Show, the dates to be decided later.

Mr. Whittelsey reported the making of definite arrangements to hold the Annual Dinner at the Hotel Pennsylvania, New York City, on Thursday evening of Automobile Show Week. The committee in charge of the Dinner has already laid out an interesting program, concerning which announcements will be made later.

Detonation Session at Annual Meeting

W. C. Keys brought suggestions from the Passenger-Car Activity regarding topics that should receive attention at the Annual Meeting. After commenting on these suggestions, the Committee discussed the allocation of Annual Meeting sessions to the various Activities. Chairman Warner asked Mr. Veal to contact with the Activities and work up suggestions, for submission to the Meetings Committee, as to how the material suggested and available could be worked into the program.

Mr. Veal brought up a request from the Fuels Research Steering Committee that a full session at the Annual Meeting be allotted to it for the presentation of papers on the subject of detonation. It would be desirable, he said, although not absolutely necessary, for the session to be sponsored by an Activity, and it would be satisfactory for it to be held concurrently with another session, if necessary. The Meetings Committee therefore voted to allow a full session for papers on detonation, to be sponsored by one of the Professional Activities or by the Meetings Committee itself.

Regarding the plans of the Diesel Engine Activity, A. J. Poole said that that group would probably not desire for some time to hold a National Diesel Engine meeting but that efforts were being made to have Diesel Engine topics discussed at Section meetings. The Committee considered the idea a good one and stressed the desirability of coordinating the meetings work of the Society with that of the Sections.

More Time for Discussion Wanted

In connection with the perennial question of arranging sessions so as to allow time for discussion. Chairman Warner suggested that the headquarters office assume definitely the duty of analyzing each particular session, examining each paper and conferring with each author with a view to helping the author to present his paper briefly, though adequately. In this connection the Committee asked Mr. Veal to formulate definite rules for handling papers at a session so as to secure ample time for discussion.

In conclusion, the Committee discussed the matter of preprints and requested that when a meeting program is published, a note accompany it, saying that preprints of papers will, when available, be furnished upon request.

October Transportation Meeting

Program Calls for Three Days of Papers, Plant Visits and Dinner

MORNING and afternoon sessions on Oct. 22, 23 and 24, a Transportation Dinner on the evening of Thursday, the second day, and visits to motor-vehicle fleet-operating plants on the afternoon of Friday, the last day, comprise the general features of the plans for the annual National Transportation Meeting of the Society, which is to be held in Pittsburgh next autumn.

The program for the meeting is largely the result of the suggestions and efforts of the Meetings Committee of the Transportation and Maintenance Activity Committee, of which Committees Adrian Hughes, Jr., and F. C. Horner are Chairman respectively. The Pittsburgh Section, under the direction of Chairman J. M. Orr, is making arrangements for the Dinner and will conduct the affair.

For the technical sessions the following speakers and topics have been selected and scheduled:

C. W. Stocks, editor of *Bus Transportation*, Requirements for Performance-Indicating and Recording Devices, Their Installation and Operation.

H. B. Hewitt, of the Philadelphia Rural Transit Co., Scientific Inspection of Motor-Vehicles and Their Units.

P. V. C. See, of the Northern Ohio Light & Power Co., Motor-Vehicle Maintenance Methods to Prevent Road Delays.

Austin M. Wolf, consulting automotive engineer, Practical Mathematics for Determining Tractive Ability.

Adrian Hughes, Jr., of the United Railways & Electric Co. of Baltimore, How Advantage Can Be Taken of the Latent Heat of Cooling Water.

James W. Trimmer, of the Carnegie Institute of Technology, How the Principles of Economics in Motor-Vehicle Transportation Are Taught by Educational Institutions.

The paper by Professor Trimmer will be supplemented by prepared discussion by J. S. Lowe, of the Northern Ohio Light & Power Co., describing the school of training established by that company for its motorcoach operators.

Frank D. Goll, of the Aluminum Co. of America, will present a paper describing the use and the possibilities of aluminum alloys in commercial motor-vehicles.

Meetings Calendar

Chicago Aeronautic—Aug. 26 to 28

In conjunction with National Air Races
Palmer House

Production—Oct. 7 and 8

Book-Cadillac Hotel, Detroit
Production Dinner, Oct. 8.

Transportation—Oct. 22 to 24

William Penn Hotel, Pittsburgh
Transportation Dinner, Oct. 23

Banquet to Rear Admiral Byrd

ON JUNE 25 the aeronautic industry paid tribute to Rear Admiral Richard E. Byrd, U.S.N., retired, and his associates for their achievements in discovery at Little America and their flight over the South Pole. The banquet, sponsored by the Aeronautical Chamber of Commerce of America, was held in the ballroom of the Hotel Astor, New York City, bringing together National figures from all branches of the aeronautic industry.

Introduced by Toastmaster James Schermerhorn, Sr., in his characteristically humorous vein, short tributes were paid by the Hon. F. Trubee Davison, Assistant Secretary of War for Aeronautics, Second Assistant Postmaster-General Glover, and the Hon. David S. Ingalls, Assistant Secretary of the Navy for Aeronautics.

Fred. B. Rentschler, president of the United Aircraft & Transport Corp. and president of the Aeronautical Chamber of Commerce, presented to Admiral Byrd on behalf of the industry a gold medal commemorating the admiral's flights over the North and South Poles. Silver replicas of the medal were given to Bernt Balchen, Harold June and other of Byrd's aides.

After accepting the medals in the name of the expedition, Admiral Byrd spoke briefly and introduced the various members of his expedition. Bernt Balchen, pilot of the plane that flew over the South Pole, also addressed the group briefly on matters of general interest regarding the flight.

Balchen, who was chosen on the transatlantic flight with Admiral Byrd, as the man best qualified to land the airplane at night in the sea with poor visibility, is a member of the Society. The guests at the speakers' table included other famous personages, most of whom are likewise members.

More than 40 other members of the Society attended the banquet, occupying a series of special tables reserved for their use.

Responding to Mr. Rentschler's presentation remarks, Admiral Byrd said in part that, as a moral and economical force, aviation has at last come under scientific control and is being directed for the infinitely larger sphere of action that awaits it. Referring to the progress made in aviation in the two years that his expedition had been absent on the trip to the South Pole he said:

"I have devoted many years of my life to aviation, and I come back now with greater faith than ever, seeing its possibilities even more than ever before, and I want to say, with all the earnestness of which I am capable, that the depression which I find in aeronautic circles from some natural overproduction is due simply to the fact that you are temporarily down in the trough of the wave. It must necessarily follow that aviation will be on the top of the wave tomorrow and as certain as the sun rises will gradually settle to its level, which will be as even, as substantial and as everlasting as the new mountains I found in Antarctica, which are made of granite and will stand forever."

MEDAL AWARDED TO REAR ADMIRAL BYRD TO COMMEMORATE HIS CONQUEST OF THE TWO POLES

The Office of the Society Will Be Closed from July 28 to Aug. 11 Because of Vacations.
A Very Few Members of the Staff Will Be on Hand To Take Care of Important Business Only.

Chronicle and Comment

Coker Clarkson, Secretary and Friend

AS THE LAST forms of the June issue of THE JOURNAL were being prepared for the press, we were plunged into deep sorrow by the unexpected announcement of the flickering out of the light that throughout almost the whole course of the Society had been the sure and unfailing beacon to show its way.

Despite Mr. Clarkson's long illness following the Annual Meeting last January, he was believed to have been recovering slowly, and only two days before the fatal termination of his sickness he had asked to see the copy of the obituary notice regarding his long-time friend and co-worker in the Society—Dr. Riker—so that he might add a personal tribute. Thus, even in his final days his thoughts were with the Society.

Nothing that we can say here can adequately express the feelings that we know affect all who knew his kindly spirit, his deep concern for the well-being of the Society, his untiring labor in its affairs, his meticulous exactness, and the soundness of his advice. His was the stalwart figure to which those in doubt carried their uncertainties, sure of receiving a calm, judicious consideration and helpful suggestions. Always genial and urbane, even when pressed with manifold concerns, he never failed to turn a sympathetic ear.

The passing of Mr. Clarkson deprives the Society of the one personality that was best known and best loved by the members and who was most instrumental in directing the Society along the lines responsible for its rapid growth and its worldwide prestige.

The many tributes paid to the memory of Mr. Clarkson in the special Dedication section of this issue of THE JOURNAL attest the admiration and affection in which he was held, not only by the officers and members of the Society, but throughout the automotive industry in this Country and in Europe.

First International Aerial Safety Congress

AN INTERNATIONAL Congress for the discussion of safety in the air and of means to hasten its progress is to be held in Paris, from Dec. 10 to 25, 1930. This is under the patronage of President Doumergue, of France. The Committee of Patronage includes the presidents of the French Senate and Chamber of Deputies and other high officials of the republic and of the City of Paris. The presidents and directors of most if not all of the aeronautic and aviation organizations of France are named on the Committee of Honor.

At a conference held at the Department of Commerce in the City of Washington last spring, at which the Society was represented by Dr. George W. Lewis, director of aeronautic research for the National Advisory Committee for Aeronautics, a decision was reached to endeavor to secure ten papers by American authorities for presentation at the Congress. Each organization represented at the Washington Conference was requested to ask his organization to submit titles of from five to ten papers, together with a recommendation as to authors to prepare them. Accordingly, for the Society, President Warner submitted such a list.

The Department of Commerce is taking the general sponsorship for America.

The Congress will be composed of honorary and adhering members. The latter, upon payment of a registration fee of 100 francs ($3.91 in American money at present exchange), will be entitled to admission and to take part in the discussions, and also to the volumes containing the reports of the Congress.

Dr. Lewis suggested to President Warner that it seems desirable that applications for adhering membership be forwarded to the organization with which the proposed member is affiliated, as the handling of the applications and funds can thus be expedited. The Society has been provided with a number of application blanks.

Summarizing Papers at Meetings

SEVERAL of the papers at the Summer Meeting sessions were presented by the authors in summarized form instead of being read in their entirety. This is a commendable growing practice; a subject can be presented much more interestingly when the speaker gives it in condensed form without reading and explains the lantern slides as they are shown. Nearly all of the papers are preprinted and distributed at the sessions, and many are mailed in advance of the meeting to members who are most likely to be interested in the subject and desire to be prepared to give written or oral discussion. The practice also shortens the time of delivery, leaving more time for discussion.

It is noticeable that members are taking part more freely in discussion and with less urging by the Chairman than in former years, and it is desirable that full opportunity be given for such expression of opinion rather than reading from the platform papers that are in the hands of those in attendance.

In this connection, President Warner suggested at a dinner meeting of the Meetings Committee, held during the Summer Meeting in May, as reported in this issue of THE JOURNAL on p. 2, that the headquarters office confer with the author of each paper with a view to suggesting how he can present his paper briefly but adequately. Members of the Committee asked that the headquarters office formulate definite rules for handling the presentation of papers so that ample time will be available for full discussion.

Vacation Closing of S.A.E. Office

THE New York City headquarters of the Society are to be closed from July 28 to Aug. 11 for the annual two-weeks simultaneous recuperative period for the members of the office staff. Several employes will remain on duty to attend to any urgent matters that may require prompt attention, but the office will be regarded as closed to routine affairs in the interim specified.

Wind Resistance of Automobiles

By FELIX W. PAWLOWSKI[1]

SEMI-ANNUAL MEETING PAPER — *Illustrated with* DRAWINGS, CHARTS AND PHOTOGRAPHS

WIND resistance becomes a more important factor in automobile speed as improvement of highways diminishes the road or rolling resistance and at 40 m.p.h. begins to overshadow the latter factor. The author discusses briefly the principles of aerodynamics and the airflow around various shapes is considered, the fact being pointed out that the coefficient of resistance to motion of a streamlined body is approximately one-thirtieth that of a flat plate having the same frontal area. The various methods of determining the air resistance of automobiles are described and briefly discussed, the author considering the scale-model wind-tunnel test method as not only the most promising but also the most convenient and the cheapest method of studying the aerodynamic properties of automobiles, particularly for determining the comparative value of the various changes in the car which the body designer might have in view.

In connection with wind-tunnel tests of automobile models in the middle of a large airstream, the author points out that the results are somewhat erroneous due to the absence of a cross-wind force which tends to push the body toward the ground. Some experiments made in the aerodynamic laboratory at the University of Michigan are then described. One investigation was that of the ground effect on typical motor-cars, which were conducted with crude models of a phaeton, a coupe and a sedan at wind velocities of 60, 70, 80 and 90 m.p.h. These tests showed that the ground effect increased the air-resistance for phaetons and coupes but decreased it for sedans, assuming in the case of the first two, the form of a negative lift that is added to the natural downward force due to ground effect. This increase produces an induced drag and therefore increases the total air resistance. In the sedan the cross-wind force takes the form of a positive lift of approximately the same value as the downward force of ground effect and hence results in a decrease of the air resistance. The effect of streamlining all parts of a car exposed in motion to the air current as a means of reducing the eddy-making item of total resistance to motion is to be made the subject of a special investigation to determine whether the resulting gain will be compatible with the necessary trouble and increase in cost of production. The effect of rounding the edges and corners of a parallelepiped was investigated as was also the effect of the beveling of the flanks. The result of these tests is a reduction in the value of the coefficient of resistance to motion.

As a result of the investigation the following conclusions are drawn: (*a*) Ground effect has an appreciable effect upon the drag or resistance to motion of an automobile, therefore the wind-tunnel tests of a single model do not permit the prediction of wind resistance of an actual car, even for comparative purposes, since the error might be from − 3 to + 21 per cent at 60 m.p.h. or from − 5½ to + 15 per cent at 90 m.p.h.; (*b*) the zero-lift condition with ground effect would eliminate the induced-drag item from the total wind-resistance, a condition that might not always be fully realizable; (*c*) the so-called perfect streamlining is not very well possible, as it would lead to longer bodies that would render the parking situation still more acute and (*d*) partial streamlining, rounding of edges and corners, beveling of flanks, streamlining of wheels and similar modifications promise a considerable reduction in wind resistance.

PARALLEL with the development of good roads comes the demand for more speedy motor-cars. This demand is being satisfied gradually by the installation of more powerful engines in cars. We have passed already the 100-hp. mark; and, although gasoline is still rather cheap in comparison with European conditions, nevertheless, the question of reducing the engine power, through reduction of resistance to the motion of the vehicle, attracts more and more attention on the part of automobile engineers.

As the road or rolling resistance diminishes with improvement of the highways, the air resistance becomes more apparent and at speeds of around 40 m.p.h. begins to dominate the road resistance. To be more clear about some of the observations, statements and suggestions regarding the problem of wind resistance, or air resistance, or, still more properly, the aerodynamic properties of motor-cars, let us agree at the beginning as to some of the principles of aerodynamics, terminology and notation.

[1] Guggenheim professor of aeronautics, University of Michigan, Ann Arbor, Mich.

A Few Principles of Aerodynamics

The theoretician still maintains that the term aerodynamics contains more pretense than substance, since in our *theoretical* considerations we still assume the existence of a fictitious, nonviscous and noncompressible fluid medium; and we should, therefore, abide by the term hydrodynamics. Nevertheless, we will overlook this objection and put forward a claim to our independence, and this for the following reasons:

(1) Hydrodynamics, although a much older branch of mechanics of fluid motion, is laboring also under the handicap of the same fictitious medium, for the well-known reason of avoiding mathematical difficulty in treatment of its problems, and in that respect, therefore, it is not any better than aerodynamics.

(2) Due to the development of aeronautics, the *experimental* phase of aerodynamics has made such rapid strides that it can be considered really as an independent and originally developed branch of mechanics.

(3) Some notable and promising attempts have been made to introduce in the theory of fluid mo-

tion the effects of viscosity and compressibility of the medium, without undue mathematical complications, bringing out, therefore, a complete emancipation of aerodynamics from the heritage of the classical old hydrodynamics, which teaches that every body is streamlined and therefore its resistance to the motion is zero.

However, the youngest branch of engineering, aeronautic engineering, has profited so much, not only from hydrodynamics but also from all the other branches of engineering and particularly from automotive engineering, to which it owes its engine, that it is a particular pleasure for every so-called aero-man to have an opportunity to repay even partially the great debt incurred.

The three fundamental laws of aerodynamics are the following:

(1) The resistance to motion is directly proportional to the density of the medium, which is expressed in mathematical symbols $R \propto \delta$ or ρ where δ is the density in pounds per cubic foot; R is the resistance, usually in pounds, and ρ is the density in slugs per cubic foot so that $\rho = \delta/g$.

(2) The resistance is proportional to the square of the size of the body, or, more correctly, to the square of any homologous dimension in the geometrically similar bodies of different sizes, which is expressed $R \propto \lambda^2$ or A, where A is an area, usually in square feet, or λ is any homologous dimension. This area A can be the square of any homologous dimension or a product of any two homologous dimensions or any area giving an idea of the size of the body. Most frequently and very conveniently, for bulky bodies like airplane fuselages or automobiles, A is made equal to the area of the body projected in the direction of motion or the maximum cross-section of the body in a plane perpendicular to the direction of motion.

(3) The resistance is proportional to the square of velocity of motion, which expressed mathematically is $R \propto v^2$. This law, discovered by Newton, on the basis of purely theoretical considerations, holds good for velocities below that of sound and therefore within the range of present velocities of traveling on land and through the air. For very slow motions and minute bodies this relation is simply $R \propto v$ as it has been discovered much later by Stokes, a British physicist, and at velocities above that of sound, which is about 740 m.p.h., $R \propto v^n$ where $n > 2$; but our ambitions do not go so far yet, even in aeronautics, and so we will let the ballisticians worry about this law.

The above three laws can be combined in this way $R \propto \rho A v^2$ and all that is necessary to convert this proportionality into an equality is to introduce a proportionality factor in the above expression, giving

$$R = k \rho A v^2 \qquad (1)$$

This factor k is usually referred to as coefficient of air reaction or coefficient of air resistance, a quantity independent of the density of the medium, size of the body and velocity of translation, but depending upon the shape of the body, its attitude relative to the direction of motion, viscosity of the medium and to some extent upon the character of the surface of the body, that is, the degree of its smoothness or roughness.

This coefficient k in Equation (1) is also a pure number; that is, a non-dimensional quantity, if the dimensions of the left and right members of the equation are in the same units as they should be, and it is also independent of the system of dimensions. This can be demonstrated by substituting for the various quantities of the equation their dimensions; for example:

A in sq. ft.

R in lb.

$$\rho = \frac{g}{\delta} = \frac{\text{lb. per cu. ft.}}{\text{ft. per sec. per sec.}} = \frac{\text{lb. (sec.)}^2}{\text{cu. ft.} \times \text{ft.}}$$

v^2 in $\frac{(\text{ft.})^2}{(\text{sec.})^2}$

$$\text{lb.} = k \frac{\text{lb. (sec.)}^2}{(\text{ft.})^4} \times (\text{sq. ft.}) \times \frac{(\text{ft.})^2}{(\text{sec.})^2}$$

all ft. and sec. items cancel out and lb. is lb. The same result for non-dimensionality of k can be obtained, also, using the metric system of dimensions. A homogeneous system of dimensions should be used, that is either pounds, feet and seconds or kilograms, meters and seconds.

The ever busy and sometimes lazy engineers, however, prefer to write this fundamental equation in a somewhat simpler form, saving, thus, one slide-rule operation:

$$R = K A v^2 \qquad (2)$$

Here K contains the air density, is no more a pure number and has different values for the English and metric systems of dimensions. Since the density of air varies with the temperature and barometric pressure it has become, therefore, necessary and customary to establish these coefficients for the different bodies at certain standard conditions. These standard atmospheric conditions are taken as 15 deg. cent. (59 deg. fahr.) and 76-cm. (29.921-in.) mercury column in this Country and all others, with the exception of Great Britain where it is 60 deg. fahr. and 30-in. mercury column. Fortunately, the difference between these two standards is slightly less than ½ per cent, which is negligible from a practical engineering point of view.

The above fundamental equation of aerodynamics, (1) or (2), while very simple, is still rather crude, that is, incomplete and inaccurate, since it does not take into account the shape of the body and viscosity of the medium; it works very satisfactorily, however, if applied with discretion and within certain limits.

We should keep in mind that in case of motion of a body immersed in the medium the total resistance to the motion can be subdivided into the following items:

(1) *Eddy-making resistance*, due to energy losses in stirring up eddies behind the body, particularly in bodies with blunt rear ends or short bodies. This resistance is also referred to as body resistance since it depends upon the shape of the body, and this part of the total resistance follows the law of the square of the velocity.

(2) *Skin-frictional resistance*, due to skin friction on the flanks of the body or portions of the body surface where the flow of air is parallel with the direction of motion or has a component parallel with the direction of motion.

(3) *Induced drag or resistance*, appearing only in cases where the body, due to its shape or attitude relative to the direction of motion, generates a cross-wind force, or a drag induced by cross-wind force. The resistance is proportional to the square of the cross-wind force.

In smoothly shaped elongated bodies, producing comparatively little eddies, the first item might be small

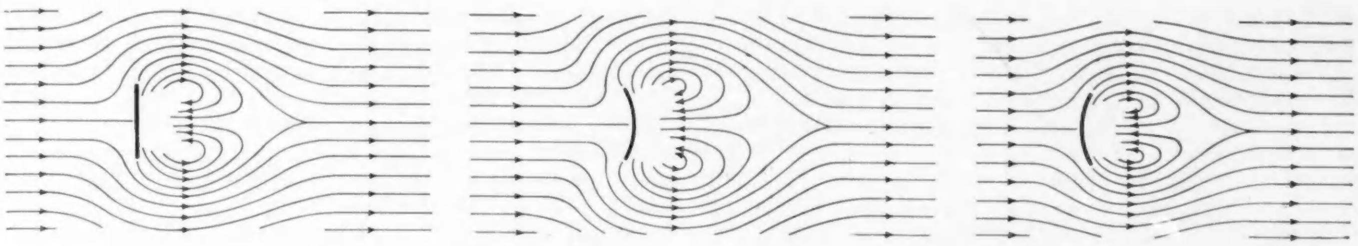


FIG. 1—EXAMPLES OF AIR-FLOW AROUND, AND THE FORMATION OF EDDIES BEHIND, A PLATE
In the Left Drawing a Flat Plate Is Normal to the Direction of Motion. In the Middle Drawing a Curved Plate Is Concave toward the Air Current and in the View at the Right It Is Convex

and the second item may then be the major part of the total resistance. Since the skin friction does not follow the law of the square of the velocity of motion, namely, the exponent is not 2 but 1.83, therefore the total drag, to use the more familiar term, in smoothly shaped elongated bodies, streamlined bodies, will follow the law of the square of the velocity with varied degrees of inaccuracy.

Neglect of viscosity has the result that measurements of air resistance obtained from small scale-models of bodies tested in wind tunnels are not directly applicable to the prediction of performance of full-size bodies. This is referred to in aerodynamics as scale effect, and the wind-tunnel data must be corrected accordingly. The effect of viscosity of the medium can be explained crudely by the simple observation that air is rather thick for a mosquito but is thin for an elephant.

To gain a clear insight of the phenomenon of air resistance let us consider briefly the flow of air around various shapes. In spite of all the imperfections and difficulties of visualization of flow of such a perfectly transparent medium, enough information on the question has been obtained to prepare drawings illustrating approximately the important typical cases.

In the left view of Fig. 1, we have a case of a horizontal flow of air around, and the formation of eddies behind, a flat plate normal to the direction of motion. The coefficient of resistance here is $k = 0.64$ for Equation (1), or $K = 0.00327$ lb. per sq. ft. per m.p.h. for Equation (2), for standard air-density and for plates of substantial size, that is, above several square feet of area. The middle drawing shows how a concave plate with the cavity facing the air current spreads apart the encountered air-current more violently, thus producing larger eddies with the resultant increase of resistance varying with the degree of camber. The drawing at the right illustrates a similar plate at a different attitude, the convex side facing the air current, with the resulting decrease of eddies and resistance to motion.

This eddying flow is not stable, of course. A pair of eddies will develop behind the plate gradually, although swelling rapidly to full size, as shown in Fig. 2, and then

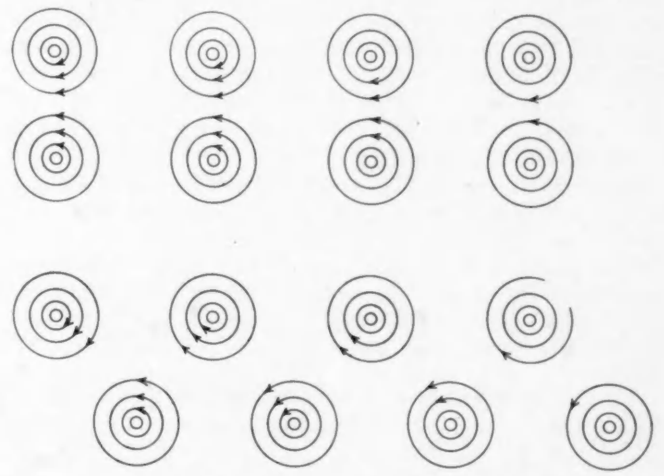


FIG. 2—EXAMPLES OF EDDY FORMATION
Periodic Discharge Forming a Train behind the Elongated Plate Is Shown at the Top. The Relative Position of the Two Rows of Eddies Is Not Stable and They Shift to the Staggered Position Illustrated at the Bottom

they will break loose allowing the formation of a new pair of eddies. It is more proper to talk about these pairs of eddies in connection with plates extending more in a horizontal direction, perpendicular to the plane of the figures, than in a vertical direction. We have, therefore, a periodic discharge of these eddies forming a train behind the elongated plate, as shown in the upper drawing. Such a relative position of two rows

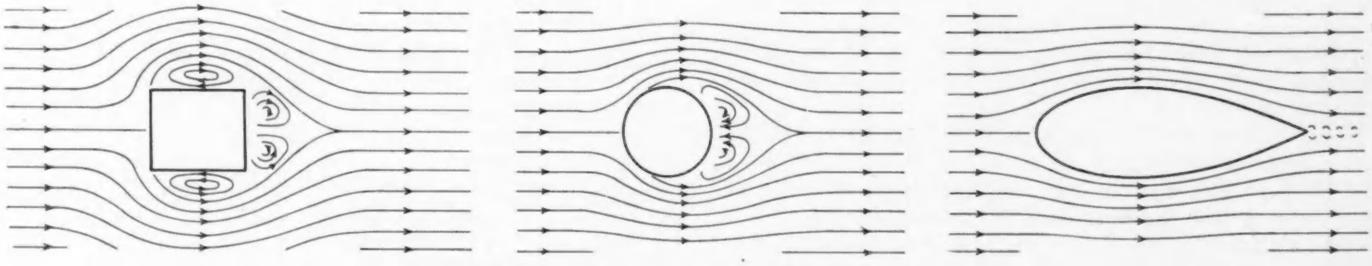


FIG. 3—HOW THE FORM OF A BODY AFFECTS EDDY FORMATION
The Parallelepiped in the Left Drawing Has the Same Frontal Area as the Plate in the Corresponding Drawing of Fig 1 and the External Outline of the Eddies Is the Same in Both. The Rounded Frontal Part of the Sphere in the Middle Drawing Facilitates the Flow of Air around It and the Coefficient of Resistance to Motion Is Approximately One-Seventh That of a Flat Plate. The Rounded Front and Pointed Rear Portion of the Streamlined Body Illustrated in the Drawing at the Right Give a Coefficient of Resistance to Motion That Is Approximately One-Thirtieth That of a Flat Plate

of eddies is not stable, however, and therefore they immediately shift to a staggered position, as shown in the lower drawing. This train of eddies is referred to in aerodynamics as the Karman street of vortices.

Fig. 3 shows at the left a parallelepiped with the same frontal area as the plate in Fig. 1. Here the external outline of the eddies is about the same as in the first case with the body of the parallelepiped displacing a large portion of the air subjected to eddying, with the result of diminishing the resistance to motion. The middle drawing shows a sphere, the rounded frontal part of which facilitates the flow of air around it, and which also displaces a large portion of air from the eddy space, with the result that the coefficient of resistance is now $k = 0.088$ or $K = 0.00045$ lb. per sq. ft. per m.p.h. or less than one-seventh as large as that of a flat plate, and finally the drawing at the right illustrates the flow of air around the so-called streamlined body where, due to the rounded front and pointed rear portions of the body, the air flows around it smoothly with the least possible disturbance, producing the least possible number of eddies. The coefficient of resistance of such a body can be as small as $k = 0.022$ or $K = 0.000112$ lb. per m.p.h., or slightly more than 1/30 as large as that of a flat plate.

Such small values, however, are realized only in the most carefully streamlined bodies, such as hulls of dirigibles. In airplane fuselages, with not as perfect shapes, although as well streamlined as is reasonably possible, a good average value of these coefficients is $k = 0.078$ or $K = 0.0004$ lb. per sq. ft. per m.p.h. or less than one-eighth as large as that of a flat plate.

Air Resistance of Automobiles

Different methods of determination of air resistance of automobiles have been suggested and used by various investigators. These are:

(1) Dynamometric towing
(2) Coasting down a hill of uniform grade
(3) Mounting an automobile equipped with dynamometers for measuring the air resistance on a flat car that is pushed by a locomotive
(4) Full-size wind-tunnel tests
(5) Scale-model wind-tunnel tests

The first method presents difficulties in accounting for the road resistance, friction losses in the wheel axles and the effect of the ever-shifting wind. To deduce the pure air resistance from such a test is really like trying to unscramble eggs.

The second method offers somewhat similar difficulties. However, in spite of these difficulties it was used very successfully at Yale University in 1928, and congratulations were due to the late Prof. E. H. Lockwood for the very uniform results obtained from tests of a variety of vehicles.

Very noteworthy results have been obtained with the third method by Prof. T. R. Agg and Noah Wolfard, of the Iowa State College and the Oklahoma College of Agriculture and the Mechanic Arts respectively.

The full-size wind-tunnel method was used for improving the design of racing cars, some 10 years ago, in the large wind-tunnel at Issy-les-Moulineaux, of the French Army Section Technique d'Aeronautique, and by Prof. L. E. Conrad and E. R. Dawley in a special large wind-tunnel at the Kansas State Agricultural College in 1925 and 1926. This method has the disadvantage of impossibility of determining the ground effect, to be explained farther on in this paper, upon the air resistance of an automobile moving along the road. Nevertheless, the work done in Kansas is most noteworthy because of the great variety of vehicles tested, 22 different motor-cars.

The scale-model wind-tunnel method is perhaps the oldest one and also the most promising. Eiffel tested models of automobiles, locomotives and railroad coaches as far back as 20 years ago in his Paris aerodynamic laboratory. He soon realized the necessity for reproducing in these tests the effect of the ground moving relatively to the car, and he tried to do this by a model of a car on a wide endless belt, this belt being run at the velocity of wind in the tunnel. However, to prevent the belt from whipping and to make it run smoothly was impossible and so the method was abandoned. Dr. W. Klemperer and P. Jaray, in their tests in 1922 in the Zeppelin Laboratory at Friedrichshafen, Germany, used, instead of the above method, a fixed large flat plate; this method, however, introduces an error due to retardation of wind flow in proximity of the plate.

Only in 1924 was the problem of introduction of ground effect in wind-tunnel tests solved in a more rational way and without any additional difficulties in conducting such tests. The credit for this discovery goes, very likely, to Prof. L. Prandtl, of the Goettingen University, under whose direction E. Rumpler, the well-known German airplane builder, made tests of models of his streamlined motor-cars, erroneously called *Wassertropfen* shaped.

The results of all the enumerated tests indicate that the coefficient K of Equation (2) for the different standard types of automobile of that time lies somewhere between 0.0014 and 0.0018 lb. per sq. ft. per m.p.h. for closed cars and between 0.0016 and 0.0026 lb. per sq. ft. per m.p.h. for open cars, that is, it is from 57 to 45 per cent and from 51 to 20 per cent respectively smaller than the coefficient of resistance of a flat plate. At a speed of 50 m.p.h. the wind resistance of the usual motor-car is between 110 and 170 lb., absorbing between 15 and 23 hp. of the engine power. At the desired speed of 100 m.p.h. this resistance will be quadrupled.

The Principle of Aerodynamic Reflection

This is the principle upon which is based the above-mentioned method of introduction of the ground effect in wind-tunnel tests of automobile models. Considering for simplicity the streamlined body of Fig. 3, we will observe that, due to symmetry of the body and the axis of symmetry being in the direction of motion, the whole air reaction will be drag, a force parallel with the direction of air-flow and, therefore, no chance will exist for obtaining a cross-wind force, a component of air reaction perpendicular to the direction of motion. If, however, the same body is moved along the ground at a distance h, as shown in the left drawing of Fig. 4, the flow of air underneath the body will be crowded, which will result in increase of velocities along the corresponding flow-lines. This increase in velocity of flow will result in a decrease of pressures along these lines, according to the well-known Bernoulli theorem, which in its turn will produce a change in the magnitude and direction of the air reaction, namely, a cross-wind force, pushing the body toward the ground, will appear. Something very similar takes place in an automobile rolling

on the road, and therefore wind-tunnel measurements made on a model placed in the middle of a large airstream give erroneous results as to the air resistance of automobiles.

By using in these tests two identical models placed one above the other at a distance twice that from the ground, as shown in the middle drawing, we obtain in the middle, between the two symmetrical bodies, a rectilinear flow-line, as if along the ground. The two symmetrical halves of this drawing are like mirror reflections, that is, one is the reflection of the other. By halving the air resistance measured on such two bodies we obtain the resistance of one body with ground effect at a distance *h*. The cross-wind forces in these two bodies result in mutual attraction of the bodies, a phenomenon well known from parallel running of boats on water.

Since generation of cross-wind force results in an increase of resistance to motion, therefore the body should be shaped so as not to produce that force in proximity to the ground. This can be done in the case of the so-called perfectly streamlined body, body of least resistance, by cambering the center line of the body a proper amount, as shown in the drawing at the right in Fig. 4.

Considering automobiles, we must keep in mind that, due to the shapes of the various types of motor-car, they may produce vertical cross-wind forces, positive or negative lift, when tested singly within an airstream of a wind-tunnel, smaller or greater than the cross-wind forces due to ground effect, when two models in opposition are tested, so that the resistance with the ground effect may be greater or smaller than without it. This would be one of the interesting things to find out, and we will proceed now with the description of some experiments made during the year 1928-1929 in the aerodynamic laboratory at the University of Michigan. These experiments were made, under my direction, by a group of students in aeronautical engineering, George C. Candler, Jr., Elizabeth MacGill, R. E. Middleton, C. I. Petcoff, Federico Wiechers and Frank Wyszynski, whose efforts and skill are hereby appreciatively acknowledged.

The Ground Effect on Typical Motor-Cars

This investigation was presented by Miss MacGill in the form of a thesis in partial requirement for the degree of Master of Science in Aeronautical Engineering. In this investigation, for lack of better ones, rather small and crude commercial cast-iron toy automobiles

TABLE 1—GROUND-EFFECT TESTS ON TOY AUTOMOBILES

Type of Car	Ground Effect, Per Cent At 60 M.P.H.	Ground Effect, Per Cent At 90 M.P.H.
Phaeton with Curtains Up	+21.2	+15.3
Phaeton with Curtains Down	+14.5	+12.6
Coupe	+ 3.0	+ 3.3
Sedan	− 3.0	− 5.5

were used. In spite of the inaccuracies of these models, a phaeton, a coupe and a sedan, they were sufficiently satisfactory for the investigation in question. Of course, the models were improved upon a little, particularly at their bottoms and the inside faces of the wheels to resemble actual automobiles somewhat more closely. The tests were made at 60, 70, 80 and 90 m.p.h. wind velocity. Since the ground effect varied gradually with the speed, therefore, for the sake of brevity, only results for the extreme speeds are given in Table 1.

This means that in predicting the air resistance of an automobile on the basis of a wind-tunnel test of a single model, that is, without the ground effect, the resistance so determined might be many per cent in error. The ground effect results in an increase of air resistance for phaetons and coupes and in a decrease in sedans.

This effect can be explained in the following way: The cross-wind force on phaetons and coupes, due to their respective shapes, at least in these crude models, is in the form of a negative lift that is added to the so-to-speak natural downward force due to the ground effect. This increase of the resultant cross-wind force results in an increase of induced drag and, therefore, in an increase of the total air-resistance. The cross-wind force on a sedan is in form of a positive lift, slightly smaller or slightly greater than the natural downward force of ground effect, so that the resultant cross-wind force, although directed either downward or upward, is, nevertheless, smaller than the natural downward force of ground effect, with the result of a decrease of wind resistance. Of course, it is possible to imagine a case of a car in which the positive lift with ground effect will be equal to the natural downward force of ground effect, thus cancelling it, that is, a car with no vertical cross-wind force when operated on the ground, which will eliminate entirely the induced-drag item from the total resistance to motion.

Streamlining of Automobiles

To effect a reduction of the eddy-making item in the total resistance to the motion of a car, streamlining all

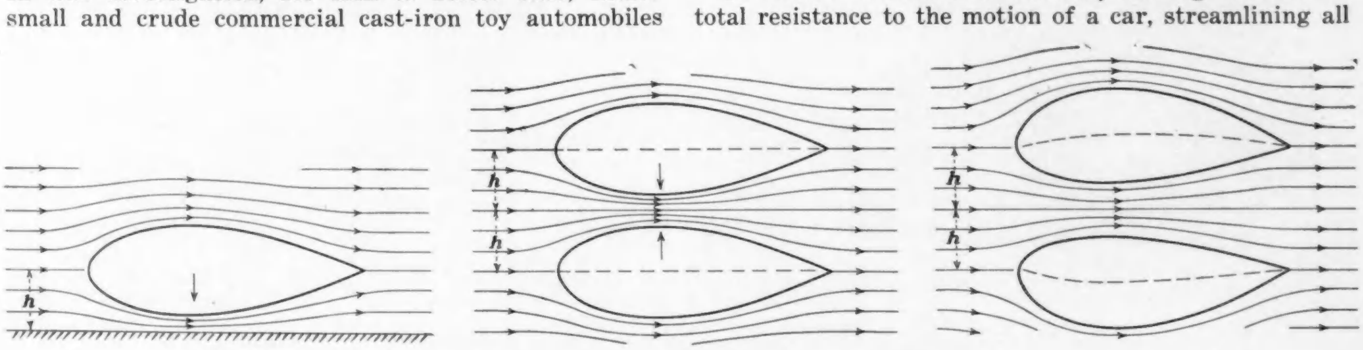


FIG. 4—PRINCIPLE OF AERODYNAMIC REFLECTION

Moving a Streamlined Body along the Ground at a Height, *h*, Crowds the Flow of Air under the Body and Produces a Cross-Wind Force Pushing the Body toward the Ground. Two Identical Models, Placed One above the Other as Shown in the Middle View, Give a Rectilinear Flow-Line between Them and the Resistance to Motion of One Body with the Same Ground Effect as the View at the Left. Cambering the Center-Line of a So-Called Streamlined Body, a Body of Least Resistance, as Illustrated in the Drawing at the Right, Will Prevent the Generation of the Cross-Wind Force in Proximity to the Ground

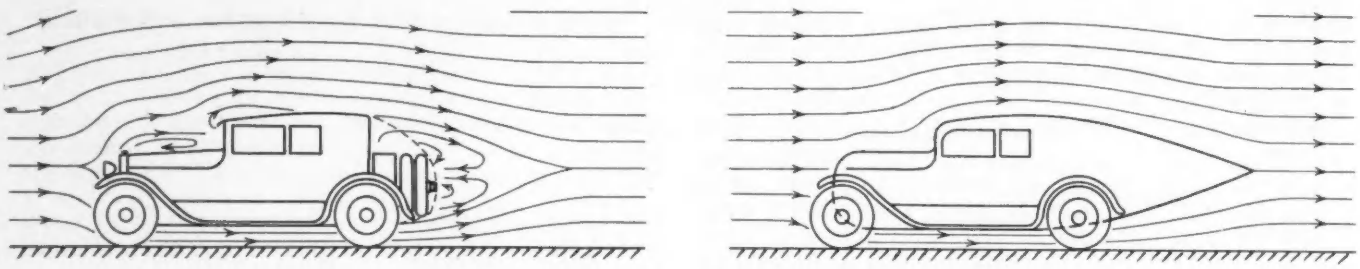


FIG. 5—EFFECT ON EDDY FORMATION OF STREAMLINING AN AUTOMOBILE BODY

the parts of the car exposed in motion to the air current would be necessary. Streamlining of axles by proper fairings, of headlights and wheels, as well as proper modifications of fenders and running-boards, will certainly help some, but whether the resulting gain will be compatible with the necessary trouble and increase of cost of production is yet to be determined by a special investigation to that effect. The major portion of the eddy-making resistance, however, is due to the bulky body of the car and therefore deserves the prime attention in this problem.

Streamlining of motor-cars would have the added advantage of not stirring up the familiar dust clouds on gravel roads. These dust clouds visualize very well the character and size of the eddies produced by the cars. A perfect streamlining of motor-cars would necessitate first of all the shaping of the body as shown in contrast by Fig. 5. A complete rounding of the front part of the engine hood and body might offer various difficulties, such as the abolition of the present type of radiator for cooling the engine, but the exceedingly long sterns would be very objectionable, at least for the already acute parking conditions. This brings up, therefore, the question of partial or incomplete streamlining of the car bodies.

In view of consideration of the flow of air around various shapes (See Fig. 3) we see that the trunks, spare tires, and other parts back of the body help in reducing some of the eddy-making resistance by displacing a certain volume of air from the eddy space. This idea could be carried out a little farther by enclosing these appendages in a casing, as indicated

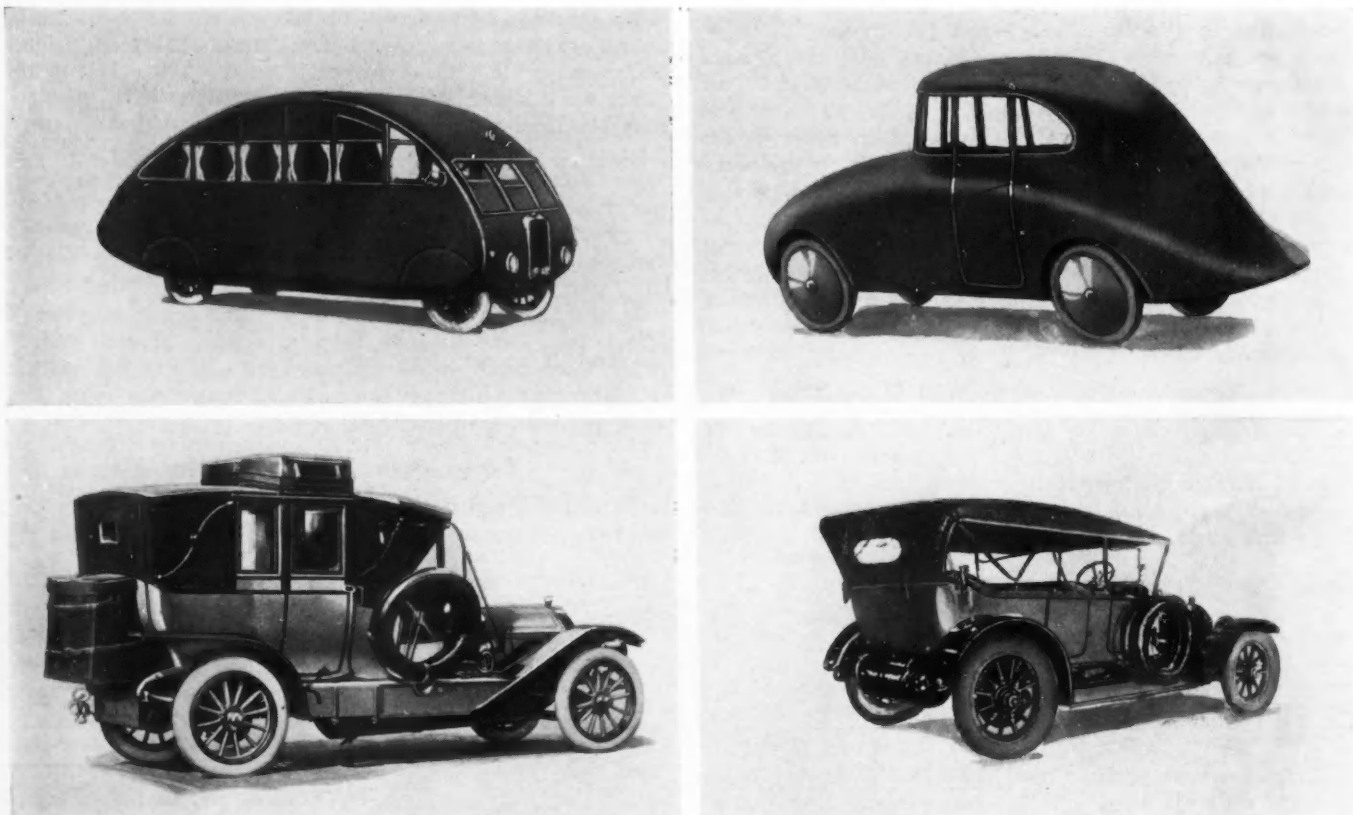


FIG. 6—EXAMPLES OF STREAMLINING OR ITS ABSENCE IN MOTOR-CAR BODIES

(Upper Left) The British Road Yacht Which Was Built around the Erskine Six Chassis and, despite Its Bulk, Developed and Maintained a Speed of 45 M.P.H. The Body of the Car Was Streamlined in the Vertical Plane Only

(Lower Left) A Closed-Car Design That Was Considered Perfect Some Years Ago

(Upper Right) A Body That Was Streamlined in Both Vertical and Horizontal Planes. This Body Was Evolved from Wind-Tunnel Experiments but Was Not a Commercial Success because of Its Departure from the Customary Arrangement of the Mechanism and Distribution of Engine and Passengers

(Lower Right) An Early Example of the Open Car

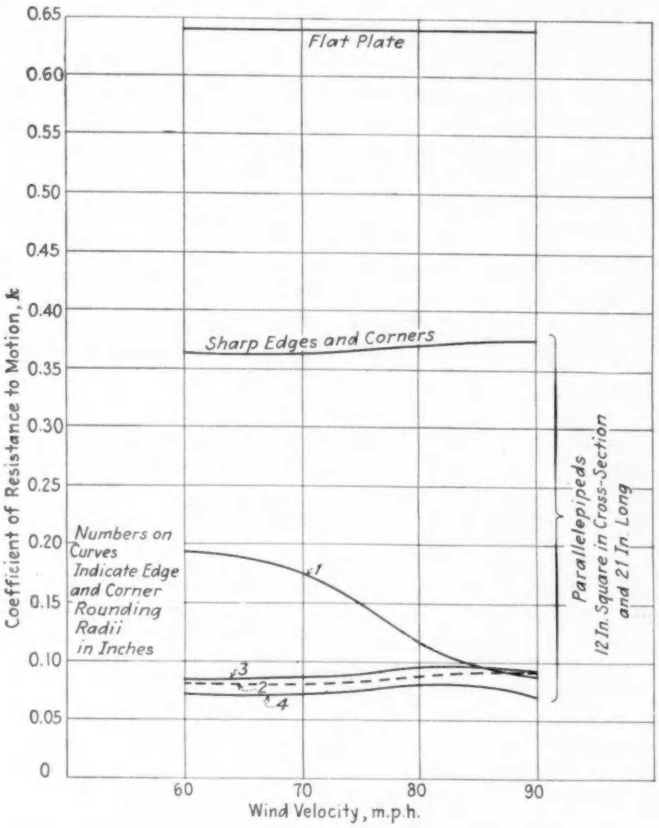


FIG. 7—EFFECT OF ROUNDING THE EDGES AND CORNERS OF A PARALLELEPIPED

In These Tests a Parallelepiped Roughly Approximating the Proportions of a Sedan Body Was Tested for Air Resistance at Wind Velocities Ranging from 60 to 90 M.P.H. and Parallel to the Long Sides. In the First Test All Edges and Corners Were Sharp and in the Remaining Tests They Were Rounded with Radii of from 1 to 4 In. as Indicated by the Numbers on the Curves. The Coefficient of Resistance of the Flat Plate of Fig. 1 Is Also Plotted for a Comparison

roughly by dotted lines in the view at the left of Fig. 5. A farther reduction of this resistance can be produced by rounding the corners of the car bodies. The necessity for this has been felt for some time by body designers as is evidenced in most of the more recent designs.

A few examples of attempts at streamlining motorcars should be briefly described here. Besides the already mentioned Rumpler *Wassertropfen* car, a British Road Yacht is shown in the upper left sketch of Fig. 6. This car was built around the Erskine-Six chassis and, in spite of its bulk, could develop and maintain a speed of 45 m.p.h. The body in this car was streamlined only in the vertical plane of space, a compromise solution at a sacrifice of a large part of the possible aerodynamic advantages. Streamlining in both vertical and horizontal planes, as in the Rumpler and Jaray cars shown at the upper right, led to complete abandonment of the usual well established and very advantageous arrangement of the vital parts of the car mechanism and distribution of engine and passengers and did not succeed practically. By way of contrast, two examples of automobile designs are shown in the lower pair of views; they were considered, and quite rightly so, as perfect, some years ago, but now they would be referred to as specimens of anti-aerodynamic design.

Effect of Rounding the Edges and Corners of a Parallelepiped

The results of this investigation are taken from a thesis for a Master's degree prepared by Frank Wyszynski of the previously mentioned group of students. To gain some idea of the effect of such modifications, a parallelepiped was used approaching roughly the proportions of a sedan body, namely, 12 x 12 x 21 in., that is, the length was made $1\frac{3}{4}$ times the side of the square cross-section. This parallelepiped was tested for air resistance at 60, 70, 80 and 90 m.p.h. wind velocity parallel with the long sides, first with sharp edges and corners and then with edges and corners rounded with a radius of 1, 2, 3 and 4 in., or 1/12, 1/6, 1/4 and 1/3 of the side of the square sections. The coefficient of resistance k was computed on the basis of Equation (1) and its values for the five different shapes and velocities from 60 to 90 m.p.h. are shown in Fig. 7 in comparison with the coefficient of resistance of a flat plate.

We can see from this diagram that (*a*) the coefficient for the sharp-edged parallelepiped is on the average 32 per cent smaller than that of a flat plate, due to displacing air from the eddy space (See Fig. 1); (*b*) even a little rounding of edges, with a radius one-twelfth of the side of the square section, reduces the coefficient 47 per cent at 60 m.p.h. and 77 per cent at 90 m.p.h. as compared with the sharp-edged shape; (*c*) with larger radii, for instance, one-third of the side, a reduction, on the average, of nearly 80 per cent can be obtained in comparison with the sharp-edged case. This

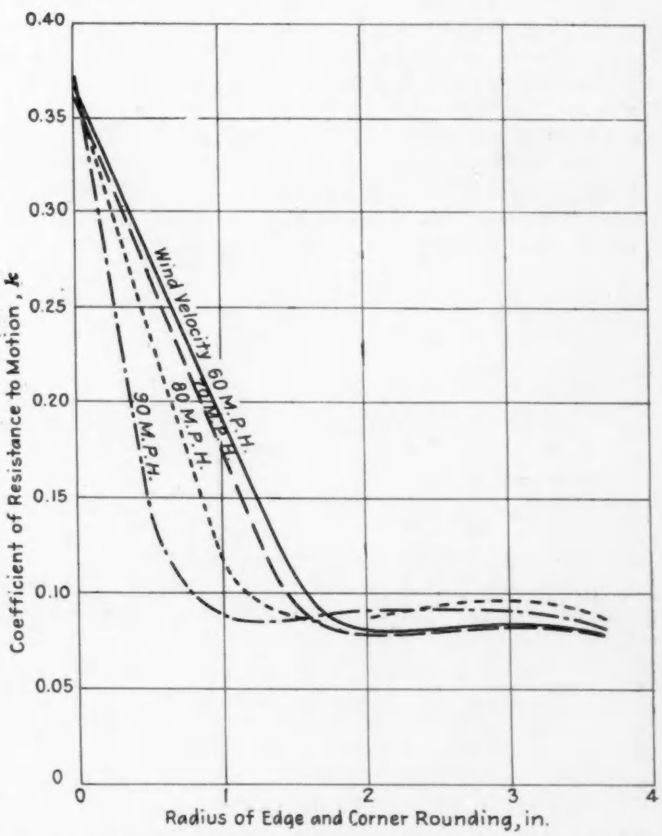


FIG. 8—EFFECT OF ROUNDING THE EDGES AND CORNERS OF A PARALLELEPIPED

The Results of Fig. 7 Have Been Replotted on the Basis of Wind Velocities. These Curves Show Clearly the Consistency of the Variation in the Coefficient of the Resistance to Motion

diagram, however, shows also that with a small radius the reduction varied greatly with the speed, that at 90 m.p.h. it can be just as great as that produced by larger radii and with larger radii the resistance passes through the minimum at smaller speeds and through the maximum at higher speeds.

The variations of the coefficient k, as shown in Fig. 7, look rather confusing and therefore they have been replotted in Fig. 8 as curves of coefficient for the different wind speeds of 60, 70, 80 and 90 m.p.h. plotted against the radius of rounding off of corners. Here the consistency of variation of the coefficient is clearly apparent.

Although the results obtained for a parallelepiped are not exactly applicable to automobile bodies, they indicate, nevertheless, at least qualitatively, that the intuition of the designers in rounding some of the edges and corners in the automobile bodies was right, but that this method should be used with discretion, or substantiated by careful aerodynamic investigation, as it might result in an increase of coefficient of resistance at high speeds.

Effect of Beveling of Flanks of Parallelepiped

To study this effect, all four flanks of the parallelepiped were beveled, as shown in Fig. 9, approximately the amount as found in modern body designs and placing the maximum cross-section at one-third of the length of the body and nearer to the front end, in agreement with the already well-established indications, in that respect, from former aerodynamic investigations. The results of the tests, in form of coefficient k of Equation (1) plotted against the wind velocity, are also shown in this drawing. The advantage of beveling the flanks, as can be seen, is very considerable.

Other experiments were made to establish the effect of sun visors; the results, however, were rather erratic and, therefore, are not presented here. In connection with a body or parallelepiped with and without beveled flanks and with some of the edges and corners rounded

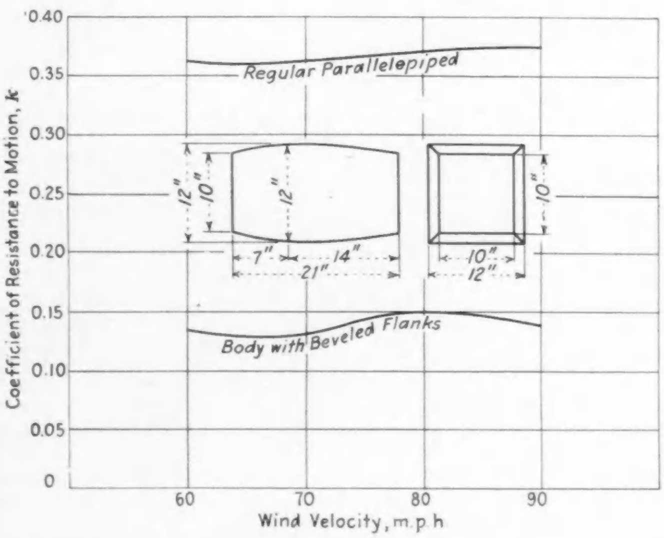


FIG. 9—EFFECT OF BEVELING THE FLANKS OF A PARALLELEPIPED

When All Four Flanks of the Parallelepiped Were Beveled, as Shown in the Insert Drawing, the Coefficient of Resistance to Motion Decreased Considerably

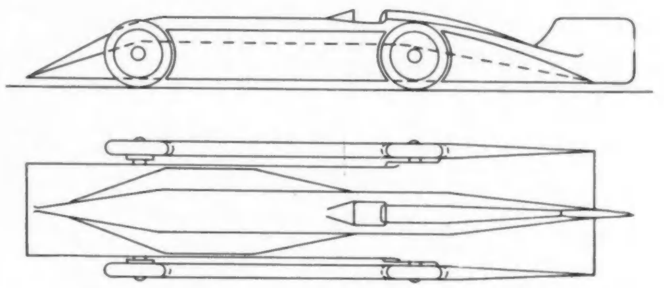


FIG. 10—DRAWING SHOWING APPROXIMATELY THE GENERAL LINES OF THE MOTOR-CAR HOLDING THE WORLD'S RECORD FOR SPEED

to different degrees, the sun visors increased and decreased the air resistance, to a small degree.

A Case of a Racing Car

A motor-car speed-record was established not long ago in this Country by a prominent foreign sportsman, and, in spite of a few attempts to do so, his record has not been bettered yet. While what will follow might be considered as criticism of the aerodynamic design of this car, that is farthest from my thoughts. What I am about to say on this point is offered with great admiration for his remarkable achievement and in a spirit of scientific interest. I trust that my comments will be received in that same spirit.

The design of this car, from a geometrical point of view, can be considered as a combination of the following bodies:

(1) A flat elongated body of a width somewhat less than the lateral distance between the wheels, thick enough to enclose the chassis together with axles, springs and similar parts, and tapered into knife-edge-like leading and trailing edges, located at the level of the bottom of the frame

(2) A round sectioned, airplane-fuselage-like body enclosing the driver and the engine, with streamlined fairings for the protruding three banks of engine cylinders, windshield and head rest and a vertical rear fin; the whole very nicely faired into the flat elongated body

(3) Four wheels streamlined by two lateral radiators fitted, as flat bodies, between the front and rear wheels and two fairings behind the rear wheels

As a matter of fact, in this way, the narrow fuselage and the wheels together with the radiators have been so well streamlined that even a slight improvement of them is not imaginable, from the aerodynamic point of view; they certainly offered the minimum of resistance to motion. The same, however, cannot be said of the flat body enclosing the chassis of the car. Here more advantageous vertical location for the leading and trailing edges could be suggested, on the basis of induced drag and ground effect. The general lines of this car are shown approximately in Fig. 10.

To verify this contention four sets of pairs of models were made of only this most essential part of the car, the flat elongated body, for the sake of simplicity. The proportions of the principal dimensions of that body were sufficiently close, for the qualitative treatment of the problem, estimated from the numerous photographs

of the car, published in the papers and showing the car from different angles of view. In one of the models the leading and trailing edges were at the level at the bottom face of the flat body, in another at the middle of the thickness of the body and at two equally spaced intermediate positions in the two remaining.

By reversing the models, seven different relative positions of the edges could be investigated for determination of the position of zero lift and, therefore, minimum drag of the body with ground effect. These positions are numbered 1, 2, 3, 4, 5, 6 and 7, as shown in the insert drawing of Fig. 11, and range from the bottom level to the top level of the thickness of the flat body in question. The tests were made at 60, 70, 80 and 90 m.p.h. and both the lifts and drags were measured with and without ground effect.

The principal results of this investigation, as taken from a thesis for a Master's degree by Federico Wiechers, member of the same group of students, are the following:

(1) The ground effect increases the drag or resistance to motion. While this increase at 60 m.p.h. was, in round figures, between 60 and 75 per cent for the different positions of the edges, at 90 m.p.h. it exceeded 100 per cent.

(2) The zero-life condition with ground effect was found between the fourth and fifth cases of position of edges (See Fig. 11) or more exactly at 28 per cent of the thickness of the flat body, measuring from its bottom.

(3) Although the measurements of small drags, on these comparatively small models, offered certain difficulties, thus impairing the accuracy of the measurements, nevertheless, smooth curves could be drawn through the experimental spots, showing that the condition of minimum drag agreed very well with the condition of zero lift, thus confirming the theory. The curves of Fig. 11 show that the minima are close to the 28-per cent-thickness positions of the leading and trailing edges of the body.

(4) The reduction of the induced drag, with the proper vertical location of the edges, is from 38 per cent at 60 m.p.h. to 20 per cent at 90 m.p.h. Since the aerodynamic theory does not offer any reasons for variation of this effect with the wind velocity, these results should be accepted therefore only as an indication of the possibility of improving the design of the particular racing car.

A further improvement, tending to decrease the drag of this flat body, could have been attained by adapting for it a well-rounded leading-edge, similar to the leading edges of airplane wings. The effect of this improvement might be small, but every little bit counts when one is attempting to establish new records.

Conclusions and Recommendations

The above considerations of the few simple principles of aerodynamics, as well as the few examples quoted, show, we hope, that aerodynamics can render worthwhile services to automobile designers in connection with their numerous problems. These examples, of course, do not exhaust the possibilities. Streamlining of automobile bodies should be more extensively studied for the effect of lateral winds, before some radical departures from the present designs will be decided upon. At high translational speeds, in strong lateral winds, serious yawing moments may come into play, impairing the directional controllability of the car. This problem should be studied with particular care in connection with the design of racing cars. Furthermore, possibilities exist of reducing the air resistance of not perfectly streamlined automobiles by artificially forcing the air to hug the body more closely, with the resultant decrease of the eddy-making resistance, but

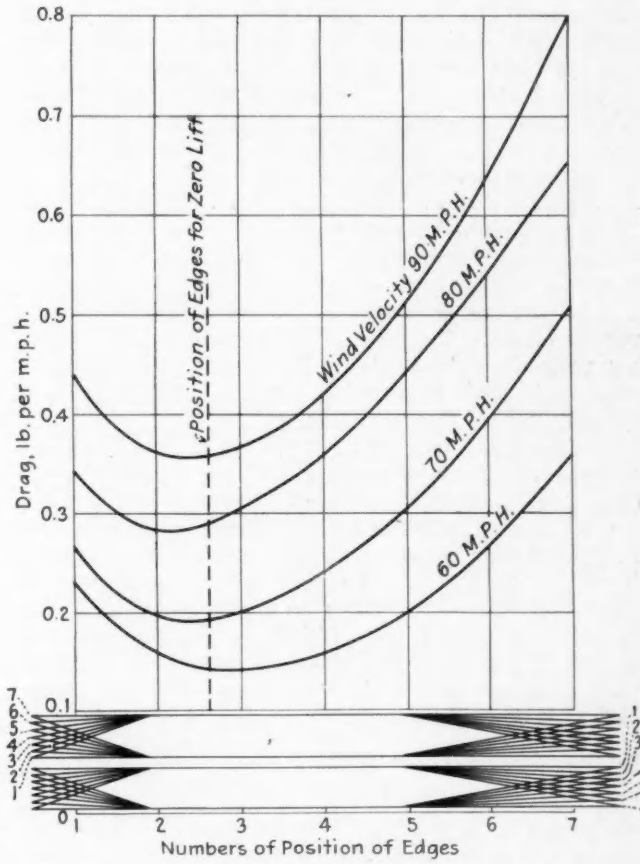


FIG. 11—VARIATION IN DRAG OF THE FLAT BODY OF A RACING CAR WITH THE VERTICAL POSITION OF ITS LEADING AND TRAILING EDGES

To Determine the Minimum Drag of the Body with Ground Effect, Tests Were Made at Wind Velocities of 60, 70, 80 and 90 M.P.H. and the Leading and Trailing Edges in the Position Shown in the Insert Drawing

the discussion of these possibilities would go beyond the scope of this paper.

In conclusion, therefore, when studying the effect of some changes in design, the wind-tunnel scale-model method lends itself as the most advantageous, since a great variety of modifications can be studied as to their *comparative* value, at much less expense, than could be done in the case of experimentation with full-size cars. The ignorance of the scale effect is here of no importance. When, however, an accurate knowledge of the full-size value of the resistance coefficient of a given car is necessary for any reason, the scale-correction coefficient could be determined by tests of a few representative designs in a wind-tunnel, using double models for ground effect, and from the full-size tests by the coasting-down-hill method. In that respect some of the Kansas, and particularly the Yale, results might be still of value.

THE DISCUSSION

E. P. WARNER[2]:—A method of measuring wind resistance which Professor Pawlowski may have hinted at or implied, but which I think was not stated directly, has been employed with very appreciable success in several cases in England. This is the use of a drawbar-pull measurement on a towed car or the measurement of resistance by coasting down a known grade, but without the necessity of making a guess at the magnitude of the rolling resistance, other than an assumption that this resistance in itself remains constant. If tests be made at a series of speeds and if the resistance be the sum of a constant figure and one proportional to the square of the speed, the latter being the air resistance, fitting the appropriate equation to the curve and finding the resistance coefficient is easy.

Professor Pawlowski's remarks on the practicability of streamlining were very striking. I think the situation is not as discouraging now as formerly for those who would seek a high degree of aerodynamic perfection. In the early days of the attempt to design streamline bodies, the ideal of the streamline was something very close to a cigar in form, but with more pointed ends. We have learned much in the last 15 or 20 years. Those of you who are familiar with the metalclad aircraft that has been several times expounded at Society meetings will recall that its over-all length is only three times its diameter. Building an automobile with the conventional cross-sectional dimensions and no more than the conventional length and with very little elongation to the tail which will still approximate the ideal in streamline form is easily possible. This design will, of course, be subject to certain modifications for fitting in the mechanical parts and allowing for the necessary breaks in the surface for the accommodation of the passengers.

Aerodynamic Reflection Method First Used in United States

One point that I will pass very briefly but I did want to get on the record has nothing to do with body resistance, but applies to a statement made in the paper which will undoubtedly become a permanent part of the literature and be subject to quotation from time to time in the future. Professor Pawlowski said, if I understood him correctly, that the method of using two objects laid face to face was originated in 1924 by Professor Prandtl in Germany. I do not know when it may have been originated, and I cannot guarantee to have traced it back to its beginning, but I do know it was used in 1916 by my former colleague at the Massachusetts Institute of Technology, Professor Ober, for measuring the resistance of a ship, models of two ships being placed face to face in that same way. Certain imperfections exist in the method. Admittedly it is the best we know of for measuring the resistance of a model, but it is not ideal, as an automobile moving along the surface of the highways entraps a certain volume of air underneath the chassis and drags it along, so to speak, over the road. A relative motion between the air and the surface of the highway occurs when we are driving with no wind, which does not exactly correspond to anything that exists where the measurement is made by the reflection method in the wind-tunnel. I suspect that difference would substantially modify the conclusions drawn about the form of Sir Henry Segrave's racing car. I imagine that an absolute and true account for ground effect, which it is impossible to get in the wind-tunnel, would have shown an appreciably better relative position for the form of chassis cover that Sir Henry actually used than was indicated in Professor Pawlowski's measurement where an apparent saving in resistance of about 20 per cent could have been made by lifting the forward and after ends of the chassis.

One of the difficulties in these racing cars is to keep them on the surface of the earth and prevent them from becoming airplanes. Although raising the ends of the chassis an appreciable distance without getting beyond the position of zero lift would, as Professor Pawlowski pointed out, be possible, still if the slightest irregularity is encountered and the car begins to bounce, we pass the position of zero lift and might turn over in the longitudinal plane.

Drawbar-Pull Method Requires Two Runs

FELIX W. PAWLOWSKI:—The drawbar-pull measurement on a towed car for measurement of resistance by coasting down a known grade, described by President Warner, would, if I understand it correctly, imply two separate sets of runs: one with drawbar on level road, with the car in tow, and the other coasting down a hill under the action of gravity with the car free. Either of these sets of runs is sufficient for determination of wind resistance, by a process as outlined by President Warner, if the rolling resistance of the car is known. In the first case we would have the method that I described as dynamometric towing; in the second, the coasting down a hill of uniform grade. I did not imply the necessity of making a guess at the magnitude of the rolling resistance, but in referring briefly to the difficulties of the dynamometric-towing method I had in mind, among others, the incorrectness of the assumption that this rolling resistance remains constant. Of course, such tests, with this assumption, have been made repeatedly in various countries, particularly in Germany. I did not know of the English tests, very likely for lack of better methods or for only a rough estimate of air resistance. Since the late Professor Lockwood of Yale found that all cars show a regular increase of rolling resistance with speed in both front and rear wheels, a total of over 30 per cent increase for speed change from 10 to 60 m.p.h., I did not feel like recommending this method, while mentioning it for the sake of completeness in enumerating the various methods used.

I agree perfectly with President Warner that our ideal of the streamline has departed very much from a cigar form. As a matter of fact, even before the World War the Italians produced a dirigible, named Leonardo da Vinci, in which the length-diameter ratio was about 3 to 1. This value of the ratio was also confirmed by a series of very systematic investigations by Dr. A. F. Zahm, in the Navy Yard wind-tunnel at the City of Washington and were used advantageously by Ralph Upson in the design of the metalclad dirigible. Fig. 5, consisting of simple lines drawn around a scale drawing of a standard sedan, by no means exaggerates the situation, as a simple measurement of the

(*Concluded on p. 86*)

[2] M.S.A.E.—Editor, *Aviation*, New York City.

Graphical Analysis of Speed and Ability

By A. J. SCAIFE[1]

Semi-Annual Meeting Paper

Illustrated with Charts

Relationship between ability and speed in the various transmission gear-ratios has been charted for a number of vehicles to show the maximum speed of the vehicle on various grades. The effect on ability and speed of changes in axle ratio are indicated in some of the charts. Road resistance is ignored in the charts, because it differs according to the tire equipment and the character of the road. These charts were made to substitute definite information for loose generalities that are based on the maximum horsepower, when the torque available at a given speed is the factor that really determines the ability. The charts shown are illustrative, and not all of them represent gear ratios and other conditions that are ideal.

WE USED to dream of the time when this Country would have all of its large centers of population connected by improved highways and our problems would be very simple. It was difficult to get a vehicle that would have enough ability and traction to get over the unimproved roads with a fair load. We were satisfied to run 10 to 15 m.p.h. on solid tires and were of the opinion that trucks could be easily standardized as to size, wheelbase and performance when the highways were all improved.

Little did we realize that good roads over long distances would bring greater problems than those with which we were then confronted. This applied not only to trucks and motorcoaches but also to batteries, generators, electrical equipment, tires and other items.

This is a day of specialization in all lines of industry and transportation. When we analyze the problems of yesterday in the light of today, we get an interesting picture.

Our problem is entirely different from that of the other organized units in the transportation field. The water routes have to combat wind and weather only, as their lanes of travel are perfectly level. The railroads have high-speed locomotives for passenger service and heavier engines operating at slower speeds for hauling freight. They operate over smooth ribbons of steel, encountering only slight grades of possibly less than 3 per cent over the greater part of their lines. Where the heavier grades are encountered, the necessary extra equipment is provided to meet these requirements—in many cases one and sometimes two extra locomotives.

With motor vehicles this is not the case. They are expected to have the speed of an express train and power sufficient to negotiate the steepest grades encountered on and off the principal highways without outside assistance.

At the Annual Meeting in Detroit last January, Dean Dexter S. Kimball, of Cornell University, presented a unique address on the Law of Diminishing Returns as applied to production. I am of the opinion that the same law could be applied to the motor-truck and motorcoach to determine the most desirable size for maximum financial return on the investment. The demand today is for equipment that will carry more passengers or greater tonnage per load or trip and do it at higher speed. This requires larger and more powerful engines, which in turn require larger and heavier transmissions, rear axles, brakes, frames and accessories of all types. Naturally, as the power and weight increase, the cost of the original equipment and of operation increases.

It is my opinion that we are approaching the point wherein the law of diminishing return is to be realized. For instance, the double-deck motorcoach is not the revenue producer that the transportation companies believed it would be in city service. While it has a seating capacity for from 48 to 52 passengers, the loading and unloading are so slow that the financial return from this equipment is not equal to that of a 40-passenger, single-deck motorcoach. My understanding is that the City of Detroit is changing over its double-deckers to the single-deck vehicles as rapidly as possible, which indicates that there is a point beyond which it is not profitable to increase the carrying capacity of passengers on a single vehicle. The same applies to merchandise. Just what will be the result along this line it is too early to predict. It may be possible that the use of trailers and semi-trailers in passenger transportation will follow, as in merchandise transportation, but we are again confronted with the question as to just how far we can go before the increase in cost is out of proportion to the increase in revenue.

The same question arises in regard to the motor-truck. Operators today are asking for motor-trucks, equipped with pneumatic tires, which will travel at high rates of speed and carry gross loads up to and exceeding 75,000 lb. over grades of from 10 to 20 per cent. Here again is a problem of finding just what the maxi-

[1] M.S.A.E.—Consulting field engineer, White Motor Co., Cleveland.

mum gross weights should be in order to get the greatest amount of profit from the investment.

Certain limitations, both physical and legal, restrict the quantity of merchandise that can be carried on a single vehicle. When greater loads are to be carried, the next step is to use a four-wheel trailer or a tractor with a semi-trailer and four-wheel trailers. While it is possible to load each vehicle, either four or six wheel, up to its physical and legal limit, the speed and ability of the vehicle must be given serious consideration.

Preventing Ill-Advised Specifications

Many operators select a vehicle without giving these matters due consideration. They ask for gear ratios that will give 35 to 40 m.p.h. without considering the ability of the vehicle to negotiate the grades encountered over a particular route, believing that they will be able to take care of the maximum loads in difficult going by simply running the engine faster. We believe that it is desirable for the operator to have a survey made of the routes over which he expects to operate, taking into consideration the maximum grades to be encountered and the type of load to be carried, whether merchandise or passengers, so that the vehicle selected will have sufficient ability in both power and speed.

Charts like those presented herewith make it possible to visualize just what can be expected from a certain vehicle equipped with predetermined tire-sizes and gear-ratios. These charts show the miles per hour of the vehicle, the revolutions per minute of the engine, the maximum grade that the vehicle will negotiate in each of the different transmission speeds or ratios, and the ability and speed of the vehicle in each of the ratios.

These charts show at a glance just what the operating conditions would be over a certain route and whether the vehicle would have the performance desired by the operator. It will show three things: (*a*) whether the engine has sufficient ability, (*b*) whether the gear ratios in the transmission and the axle are satisfactory as to speed and power, and (*c*) whether the load to be carried is excessive.

Any vehicle has a certain amount of ability, and it can be utilized in three ways: (*a*) for high speed, (*b*) for heavy work, and (*c*) part of the ability can be used in moderately high speed and part in work.

Engine Torque Determines Ability

An engine curve probably will show the maximum horsepower at about 2200 to 2400 r.p.m., whereas the maximum torque is at around 1000 r.p.m. The engine cannot be kept up to 2200 r.p.m. on any considerable grade unless it is a big powerplant, but we all talk horsepower and figure torque. The charts herewith are an attempt to bring out the true conditions.

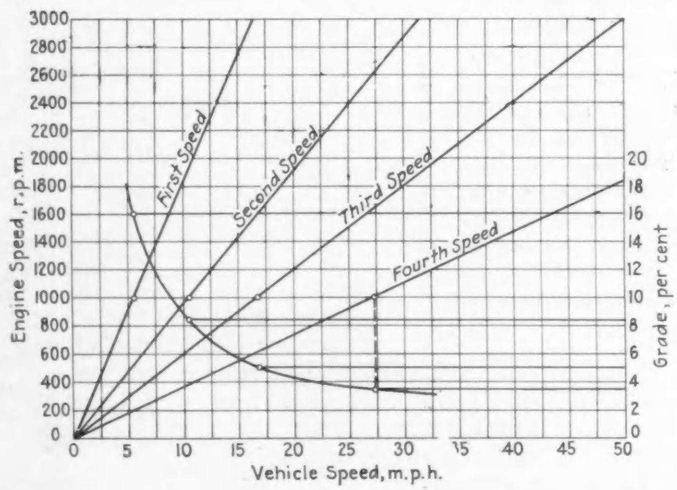
Fig. 1 is the first attempt at this work. While it shows the ability zone of each transmission-gear speed under given conditions, it shows only the maximum ability in each transmission-gear zone. It also shows the relation between road speed and engine speed in each zone, but it does not show the range of ability.

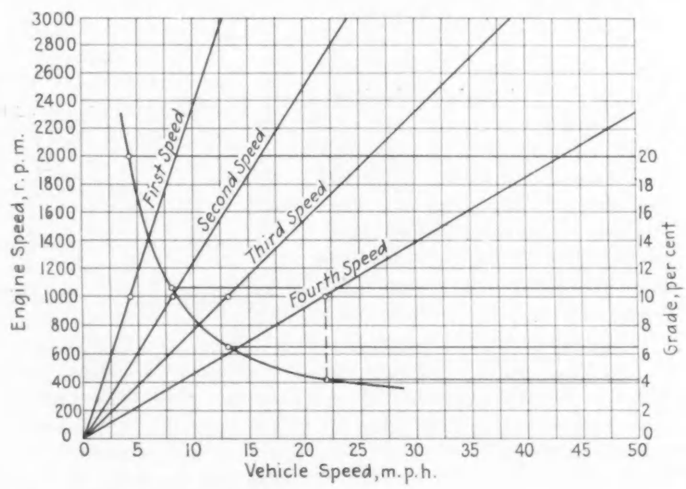
The scale at the right represents the grade without the rolling resistance, because the rolling resistance varies according to road conditions and with solid, pneumatic or balloon tires. The curve really represents a reversed torque curve. The motorcoach represented in Fig. 1 can make about a $3\frac{1}{2}$-per cent grade at 50 m.p.h., the engine then rotating at about 1825 r.p.m. As the grade increases, the engine speed is reduced to 1000 r.p.m.. which is the point of maximum torque. If rolling resistance or momentum were considered, the power curve would drop right off from that point, because the torque curve declines below 1000 r.p.m. This corresponds to about $27\frac{1}{2}$ m.p.h., on the vehicle represented in the chart. If the operator holds down the speed and shifts gears at 20 m.p.h. he moves over to the next zone, in which his engine speed at 20 m.p.h. is well above 1000 r.p.m.

Fig. 2 is of the same vehicle that is represented in Fig. 1, with the exception of the gear ratio in the rear axle, which has been changed from about 4:1 to 5:1, resulting in greater ability.

Charts Show Ability at Any Speed

Later charts show not only the maximum ability in each gear zone but also the maximum ability available at any speed in the zone, so that it is possible to tell at a





CHARTS SHOWING MAXIMUM ABILITY OF VEHICLES

No Allowance Is Made in the Charts for the Road Resistance, Which Is Not a Constant. The Diagonal Lines Represent the Various Speed Ratios in the Transmission

Fig. 1—Motorcoach Having 4.09:1 Axle Ratio and 38-In. Tires

Fig. 2—Same Motorcoach as Represented in Fig. 1, except for a 5.11:1 Axle Ratio

glance what speed the vehicle can make on any grade. Fig. 3 represents a vehicle differing from that charted in Fig. 1 chiefly by having a somewhat greater gross-weight. This shows that the vehicle can run in high gear at governor-controlled speed up to a grade of about 3 per cent. If the operator shifts gears on a grade at any point between 25 and 35 m.p.h., the governor will go into action again and keep the engine speed at 2100 r.p.m. up to a grade of 4¼ per cent. It is better to run at about 21 m.p.h. on the governor in second speed, when the engine is slowed down again by the grade in third speed, rather than to pull along at about 16½ m.p.h. It saves the engine and the whole of the mechanism, and it is always better to have a reserve of engine torque available. The chart shown in Fig. 4 is of a motorcoach like that represented in Fig. 3, except for a change in gear ratio. Figs. 3 and 4 bear the same relation to each other as do Figs. 1 and 2.

Results of an incorrect gear-ratio are portrayed in Fig. 5, which represents a heavy-duty four-cylinder motor-truck having a low axle-ratio. It will be noted that the engine torque is below the maximum in every case, and that the engine speed is reduced below the efficient point before it is possible to shift into the next lower gear. This arrangement would give fairly good road speed on the level, but the performance in a hilly or rolling country would not be satisfactory.

Transmission speeds having too great steps are illustrated in Fig. 6, which is a chart for a heavy-duty six-cylinder motortruck and tractor having a gross load of 70,000 lb. The vehicle is fitted with a seven-speed transmission, but only the four speeds in the lower range are illustrated in the chart. The transmission speeds can be seen to be too far apart, making the shift from one gear to the next almost impossible. The load has to be accelerated in each gear, which slows down the operation and places severe stresses on the rear axle and other mechanical parts.

The same vehicle with a four-speed transmission having a maximum reduction of 6½:1 in first gear is charted in Fig. 7. This makes the gear shifting much easier and gives a more nearly uniform flow of power through the entire range.

A light, high-speed motor-truck showing very desirable overlap in transmission ratios is charted in Fig. 8. This gives a very uniform power distribution over the entire gear range. Grades up to nearly 4 per cent can be climbed in fourth speed.

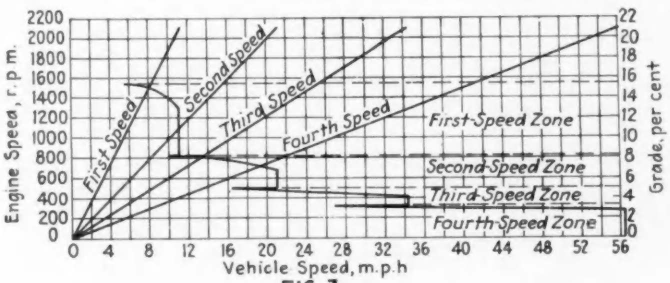


FIG. 3

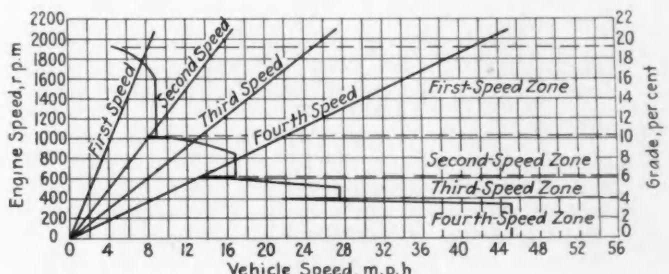


FIG. 4

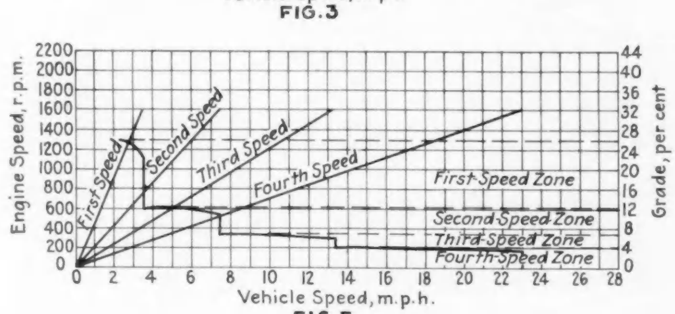


FIG. 5

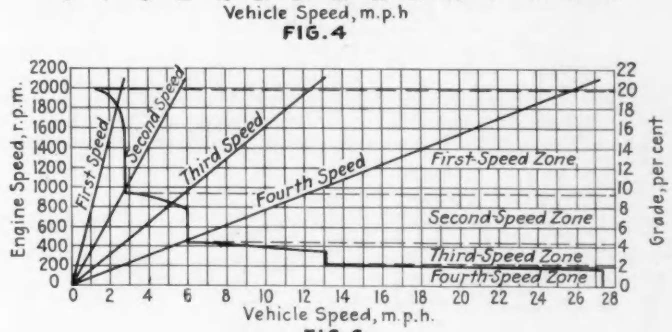


FIG. 6

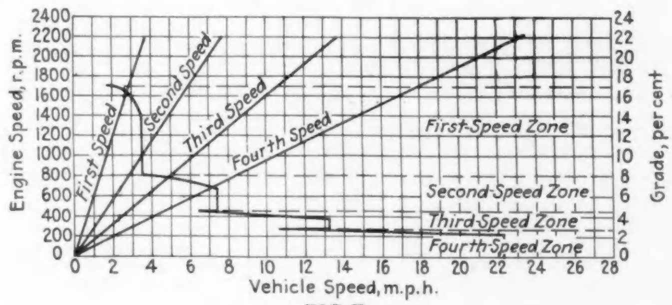


FIG. 7

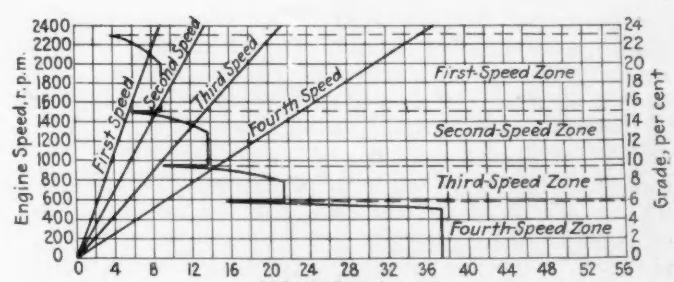


FIG. 8

CHARTS SHOWING PERFORMANCE OF VEHICLES IN VARIOUS TRANSMISSION GEAR-RATIOS

No Allowance Is Made in the Charts for the Road Resistance, Which Is Not a Constant. The Diagonal Lines Represent the Various Speed Ratios in the Transmission

Fig. 3—Motorcoach Having 38-In. Tires and 4.09:1 Axle Ratio

Fig. 4—Motorcoach Like That Charted in Fig 3, only Having 5.11:1 Axle Ratio

Fig. 5—Heavy-Duty Motor-Truck Having 36-In. Tires and 7.6:1 Axle Ratio

Fig. 6—Tractor and Trailer Having 42-In. Tires and 10.16:1 Axle Ratio

Fig. 7—Tractor and Trailer Having 42-In. Tires and 11.85:1 Axle Ratio

Fig. 8—Motor-Truck Having 32-In. Tires and 6.33:1 Axle Ratio

The Trend *of* Motorcoach Design

By FRANK R. FAGEOL[1]

Transportation Meeting Paper

Illustrated with Photographs

THE AUTHOR believes that the tendency toward change in design, whether in railroad, aviation, street-car or other practices, expresses itself more often in the larger units of these activities, as exemplified by the advent of double-deck motorcoaches. But he has noted the expression of a definite desire throughout metropolitan cities to abandon the double-deck-motorcoach operations as a result of the advent of the so-called 40-passenger type of urban motorcoach at a weight commensurate with that of the 29-passenger motorcoach.

His company's presentation of the 40-passenger motorcoach with two small engines placed amidships and the body and chassis integral, the author says, initiated a definite new and permanent trend in motorcoach design which furthered the recent general tendency toward the use of single-deck vehicles designed for larger reserve-capacity. He states his belief that the future motorcoach, as well as the motortruck and the delivery vehicle, increasingly will be designed upon analyses of the particular transportation service involved. Lowered center of gravity, economy of street space and short turning-radius are salient factors, and he believes that the attempt to secure reserve capacity by an elongated conventional motorcoach chassis will not prove practicable. Maneuverability is lost in such cases, in some types the driver's vision is seriously hampered, and it seems impossible to keep the weight within reason.

Much better results can be obtained for the larger motorcoaches by using two comparatively light-weight six-cylinder engines, the author states; but automotive practice has not yet provided clutches, transmissions, driveshafts or rear-axle drive-mechanism sufficiently large and strong to withstand the stresses set up by a single 150-hp. engine.

Motorcoach schedules can be adequately maintained without exceeding a speed of 45 m.p.h., according to the author. His company has recently developed a speed signal that warns the driver by flashing a light when the engines have almost reached their predetermined maximum speed and actuates a buzzer or bell when this speed is reached, so that the passengers are made parties to proper operating supervision.

In the discussion it was said that safety and control at dangerous speeds are not specifically an engineering problem of better brakes, but very largely a matter of driver control. F. C. Horner agreed that driver control is extremely important, but also insisted that the brakes must be adequate in that the driver must have dependable machinery available in an emergency. Other subjects included the tendency of passengers to urge a driver to travel faster, no matter how fast the vehicle may be running; what the maximum deceleration provided by the braking system ought to be and the suggestion that operating companies which have had few or no accidents with motorcoaches should analyze the reasons therefor to determine exactly why the operation of the vehicles is successful.

IN ANALYZING the trend of motorcoach design, it seems to me that an answer is expected to the question: What change in design, if any, tends toward better earning power? This may be either in the form of reduced maintenance or greater carrying capacity for the maintenance money expended. I believe that, generally speaking, tendencies toward change in design—whether it be in railroad, aviation, street-car or whatever practice—express themselves more often in the larger units of these activities. In the motorcoach field, we saw it with the advent of the double-decks. In this connection, it is interesting to note that a definite desire is expressed throughout the metropolitan cities to abandon double-deck operations, which decision arrived with the advent of the so-called 40-passenger type of urban motorcoach at a weight commensurate with that of the 29-passenger vehicle; (See Fig. 1, which shows also the parlor-car type).

Why this move has been made is well expressed in a recent letter from the operating manager of one of the three largest users of double-deck equipment. He wrote to another representative metropolitan manager that his decision to eliminate double-decks was because an analysis showed that a single-deck 40-passenger motorcoach earned about 8 per cent more than the double-deck, that this increase was caused by the ability of the 40-passenger motorcoach during peak-hours to accommodate 25 per cent more passengers than the double-deck vehicles and that the operation cost of the 40-passenger single-deck coach was 12 per cent less than that of the double-deck type formerly used.

Further, it is interesting to note that the *Electric Railway Journal*, in the paper entitled New Objectives Govern Vehicle Design[2], expressed the belief of Clifford A. Faust, assistant editor, that the two basic capacities of coaches would hereafter be the 21 and the 40-passenger types, and that the 29-passenger type was seeming to eliminate itself from its former position of importance. In a digest of the capacities of coaches[3] used and purchased by the American Electric Railway Association's members in the last year, the 21-40 classi-

[1] A.S.A.E.—President, Twin Coach Co., Kent, Ohio.

[2] See *Electric Railway Journal*, Sept. 14, 1929, p. 929.

[3] See *AERA*, November, 1929, p. 671.

fication again emphasizes itself, particularly in the tremendous increase in capacities of from 35 to 40 seats. It seems, therefore, that the major trend in motorcoach design is in connection with the so-called reserve-capacity vehicles. With the eventual complete replacement of street-cars by motorcoaches conceded in cities up to 500,000 population, and large expansions in motorcoach operations in cities having a population of more than 500,000, there is that same demand for the reserve capacity which made possible successful street-car operation in former days at a very nominal rate of fare. The street-car has been, in urban transportation, the vehicle having the most flexible capacity.

The basic elements in the foregoing set-up presented themselves forcefully to me 3 years ago, and they resulted in our presentation of the 40-passenger coach with small engines placed amidships, and with the body and chassis integral. This was a definite new trend in motorcoach design and we believe it has been instrumental in the recent general tendency created toward the use of single-deck vehicles of larger capacity. It seems that this attempted design for reserve capacity does mark a definite, permanent trend in motorcoach design and the point for discussion seems to be: What is the proper method for attaining this desired end?

Method for Securing Reserve Capacity

It was imperative in securing this reserve capacity that weight be kept in control. Therefore, our plan was to eliminate the expected increase in weight in a larger-capacity vehicle by avoiding the conventional dual arrangement for separate body and chassis and by using two small engines to circumvent the increased weights of parts required by the necessarily enlarged engine-size for increased capacity. Even though it had not seemed necessary to provide the urban operator with greater capacity, we would have considered seriously the building of body and chassis integral because of the general deterioration we always had to fight as a result of the concentrated strains at the dash of the old conventional type of motorcoach, in which the design was faulty as compared with that of today.

Fig. 1 — Parlor Car and Urban Types of Twin Coach

We believe that the future motorcoach, as well as the motor-truck and the delivery wagon, will be designed more and more upon the analysis of the transportation work involved, rather than by following the automotive grouping-scheme developed in the first passenger-cars and motor-trucks and religiously adhered to since that time. We see no reason why either trucks, delivery wagons, or motorcoaches should in any way resemble the design of a privately owned automobile.

In the door-to-door delivery field which we have been investigating recently, we find that the same habit has continued to exist; that is, trying to adapt the passenger-car scheme and the dual arrangement of separate body and chassis, instead of searching for an integral design. Lowered center of gravity, economy of street space and short turning radius are salient factors gaining little improvement under conventional arrangements. We do not believe that the attempt to secure reserve capacity in motorcoach units by using an elongated conventional chassis will prove practicable. In some of these types of unit maneuverability is lost and the driver's vision over the necessarily greatly enlarged hoods and radiators is seriously curtailed. Further, in this design of enlarged unit, it does not seem to be possible to control the weight, even by using costly materials of the aluminum type.

In facing the question of the greater power-requirements involved in larger coaches, it seems logical that much better results can be obtained by the use of two comparatively light-weight six-cylinder engines rather than by the use of one large engine. In the light engine we have all the background and experience of the manufacture of say 40,000,000 engines, but in the large-engine field there are still many unexplored problems for the final development of which the present-day motorcoach-field, with its narrow margin of profit, cannot afford to wait. For example, automotive practice has not yet provided clutches, transmissions, drive-shafts or rear-axle-drive mechanism sufficiently large and strong to

take the stresses set up by a single 150-hp. engine. It is my opinion that, when suitable designs in this field have been derived, it is probable that the weights will be substantially increased. This increase may reach the point where it will be necessary to start all over and design larger engines again. This seems to me to be an endless vicious cycle.

Maximum Coach-Size Still Undetermined

We are not at all sure that the present 40-passenger coach represents the maximum size that will be needed for the future. But we believe that the present size probably will not be increased because the 40-passenger coach represents about all that one man can conveniently operate, collect fares, and adhere to a schedule acceptable to the riding public. Hence, if larger vehicles are to be considered, it probably will mean that two men will be needed to operate them or that the schedules must be slowed up, either of which factors might offset the advantages gained. To satisfy ourselves with the actual situation in this respect, we already have designed an 8-wheel, 60-passenger coach, approximately 45 ft. in length.

Although we are adapting the integral-unit theory to the 21-passenger field, I shall not go into the design of the smaller coach at this time. While the smaller coach is a necessity, complete coach-system operation must necessarily still depend for its existence upon the cushion of earnings available from that part of the system which comprises truck routes, operating large-capacity units. As is undoubtedly known, our greater transportation systems get the bulk of their earnings from certain trunk lines, and feeder lines are operated generally as necessary evils in the way of showing an organization's willingness to shoulder the full transportation requirements of the community. Let me repeat, all of us must find the proper large-reserve-capacity unit to make general motorcoach operation a success and furnish the margin necessary for the supplementary operation of small coaches.

Wheel Housings a Handicap

Perhaps the greatest single problem to overcome in coach design is the wheelhousing interference to comfortable seating. We are hopeful that the tire companies may be able to develop a so-called "doughnut" tire of the kind now used on airplanes, and that they will be able to construct a 14-in. cross-section with only a 6-in. hub-diameter, permitting an over-all length of tire of 30 or 32 in. This would make it almost possible to eliminate the wheelhousings, and thereby again add to the always important additional reserve capacity. It would also make it possible to obtain a still lower coach.

Diesel Engine a Possibility

The cost of power for a large motorcoach is becoming an increasingly important matter because of the demand for a more rapid rate of initial acceleration, so that the rate of mortorcoach acceleration may coincide with that of the private automobile.

We have been watching carefully the development of the Diesel-type engine, which may have considerable future promise in our industry; but, I feel that it will take at least 5 years for any real progress to be made along this line. In Germany, a comparatively light type of high-speed Diesel-engine is being used to some extent on motor-trucks, but I understand that these same engines have in some instances been barred out of service in cities because, under certain conditions, they smoke and create bad odors. Should the Diesel engine become practical for use in motorcoaches, it is possible that the electric type of power transmission may be used with it.

Speed and Driver Control Discussed

Perhaps the greatest single phase of motorcoach operation needing immediate attention is that of speed and driver control. The speeds at which motorcoaches are now traveling on our interurban routes is, in many cases, far in excess of the vehicle limitations of the highways and of that for which motor-vehicle brakes and tires were designed. When one attempts to propel a vehicle weighing 14,000 to 18,000 lb. loaded with 25 to 40 passengers at speeds of from 50 to 70 m.p.h., great danger is involved in the event that any one of a dozen uncontrollable things happen.

We are convinced that most schedules can be maintained adequately without a single motorcoach exceeding a speed of 45 m.p.h. To this end, we have recently

FIG. 2—TWIN COACH SPEED-SIGNAL DEVICE

developed what we call a "speed signal" (See Fig. 2). It might be termed an animated speedometer. The function of the signal is to warn the driver by flashing a light over his head when the engines have almost reached their predetermined maximum-speed. The device further brings into action a buzzer or bell as soon as the predetermined speed is reached. Both the light and the buzzer attract the attention of the passengers, thereby guaranteeing that the passengers are made indirect parties to the proper supervision of the vehicle's operation. While this signal was developed for use on our own vehicles, we are arranging to make it available for all makes of motorcoach. Its appeal to State

Utility Commissions and to insurance companies has been remarkable.

In the design of motorcoaches, the engineers are to have a new and powerful ally in the well-organized steam-railroad motorcoach-maintenance divisions. In those divisions there is a background and the necessary pride of profession which will guarantee new standards of motorcoach maintenance.

THE DISCUSSION

F. C. HORNER[4]:—Whenever this question of brakes and speed is brought up, it incites me to say something about the necessity for preventing accidents. High speed and inefficient brakes undoubtedly cause accidents. We have been having entirely too many accidents in motorcoach transportation during the last year for the good of all concerned; primarily, on account of the passengers, and secondly, but very close to being first, on account of the operating expense. Mr. Fageol's signal system to warn the driver when he approaches a dangerous speed and that this signal also warns the passengers is an entirely new idea to me. It sounds very interesting. We cannot afford to have the riding public get the impression that all we are trying to do is to fulfill close schedules by traveling at dangerous rates of speed with heavy vehicles, loaded to capacity and equipped with brakes that cannot handle them. A very bad accident occurred on one of the motorcoach lines running out of Chicago recently, and the ticket agent told me that the traffic dropped off very sharply the following day. He said further, "the accidents that we are having are hurting our business."

It is of paramount importance for all those connected with the handling of passengers and freight to focus their attention and thought on this problem of how fast the vehicle should travel and how quickly it can be stopped. At an American Railway Convention at Atlantic City where the latest types of steam and electric locomotives were on exhibit, I said to an old, grizzled locomotive engineer: "It must be some job to run this engine." "Well," he replied, "it ain't so much of a job to run it as it is to stop it when you get it going." That is the problem with operating motor-vehicles, specially motorcoaches.


ROSS SCHRAM

ROSS SCHRAM[5]:—Supplementing what Mr. Horner has said, I do not believe, and I think our company does not believe, that the remedy is particularly an engineering problem of better brakes. The whole thing seems to us to be a matter of driver control. In the urban street-railway industry many motormen long past their youthful alert days operate through congested sections of large cities without an accident for periods of several years. In the interurban operation of motorcoaches, particularly, the vision of the driver is generally almost unobstructed. He has no high buildings or sharp obstruct corners to handicap him. Our plan is to send a driver out and endow him with the feeling that he has as much responsibility as has the captain of an ocean liner. He is supreme in command until he arrives at the next terminal. He maintains no constant speed so long as he arrives at the terminal within a reasonable nearness to the printed schedule. At some of the rest stations, the driver may wait from 5 to 15 min., because he knows he has power enough to make up that time, and he tears down the road to make it up.

Benefits of Speed Signal

In developing this speed signal, the only hope Mr. Fageol saw was to bring in the passengers as an indirect element in driver control. He felt that the engine governor is a dangerous device at present because of narrow roads when, on a holiday or a week-end, the coach has to turn in and out. A daring driver may try to make the next gap in the line and, if the engine is governed, he may find that he cannot make it, and something happens. We feel it is not an engineering problem; it is a problem of driver control in a more expansive field of operation of motorcoaches in which constant scheduled-speed and rigid adherence to it by the driver will be developed.

MR. HORNER:—I was not attempting to put all the burden on the design, material and construction of brakes and engines. Driver control undoubtedly is a most important element; but, referring to the street-car motorman who travels through congested streets and has a clean record, has anyone noticed the speed with which he can stop a big street-car? That answers the question of whether good brakes are necessary.

On a good, wide, open road, a motorcoach can make good time, say a maximum of 40 to 45 m.p.h. The coach and say 20 to 30 passengers weigh 12,000 to 20,000 lb. The driver, when he gets ready to stop, must have some adequate means of stopping that vehicle. He has to have good machinery available and must use his head when emergency arises.

A. M. WOLF[6]:—Mr. Fageol is evidently pioneering a new attitude on behalf of the motorcoach operator, in letting his passengers know what is happening. On most motorcoach instrument-boards the speedometer is immediately in front of the driver, seemingly to hide it from the passengers. Probably, if this thought of a signal device takes hold, the speedometer will go out to the middle of the instrument-board again.

MR. SCHRAM:—We had this speed-signal device on exhibition at Atlantic City, and perhaps one person out of five would say very definitely, "Yes, that is a good idea, but I would not permit it on my vehicles. If an accident occurs, every passenger will testify that the

[4] M.S.A.E.—Assistant to vice-president, General Motors Corp., New York City.

[5] Vice-president in charge of sales, Twin Coach Corp., Kent, Ohio.

[6] M.S.A.E.—Automotive consulting engineer, Newark, N. J.

driver was exceeding the speed limit. Therefore, we should have nothing like that on the vehicle." What opinion have those present on this interesting trend of thought?

Public Desires Too Great Speed

A. A. LYMAN[7]:—One thing has not been touched on; it is the fact that such a large percentage of the public really wants to ride too fast. All of our motorcoaches are run on schedules and the speeds are automatically maintained within safe limits. But, in several cases on motorcoaches that were chartered for special service, passengers urge the driver to go faster, and it seems not to make much difference how fast he goes; they still want him to go faster. In many cases passengers have even given the driver $5 to get them to their destination at a certain time.

MR. HORNER:—In reply to Mr. Schram's question, I will support what Mr. Lyman has just said. A case in point illustrates how fast people want to travel and it also proves that we now have motorcoaches so well designed and constructed that one does not realize how fast they travel. A lady who has always been rather timid about driving a car got a little better one this summer, one that was easier to handle and which was capable of greater speed. She and her young daughter made a 100-mile trip recently, and I asked the little girl how fast they were traveling. She answered: "I saw the speedometer at 60 and 65 and once I saw it at 70 miles an hour." But the lady denied it and said: "I know I wasn't going at any such speed as that." This goes to show that one can slip along at a high speed without realizing it.

A. S. MCARTHUR

I think that the objection to cutting down the speed would not be very strong, because the majority of passengers, if they knew they were going 40 m.p.h. in a big motorcoach, would be well satisfied if the schedules maintained assured them of reaching a given place at a certain time. Operating on schedule time is a very important matter.

In looking over some statements of motorcoach operations in the Southwest where road conditions are terrible, I found that the company's average of "on-time" arrival at various points was about 95 per cent. I think that is the important thing from the standpoint of the riding public. If passengers expect a motorcoach to reach a certain point and it is there on time, they learn to depend on that service as being reliable.

MR. SCHRAM:—On two vehicles tested in the Pennsylvania mountains, one was equipped with this speed signal and one was not so equipped. On the trip of say 80 miles, one driver strictly obeyed that signal light in the lower speeds, and the engine was given every chance for itself and for a well-regulated speed. On the other job, the driver was allowed to use all the power he had at any of the speeds. The driver who obeyed the signal in the low speeds came into the terminal point almost on the tail of the other driver's coach. The wear and tear on the vehicle equipped with the speed signal was nothing as compared with that on the other coach, which shows that the signal may really be very advantageous in the matter of maintenance.

CHAIRMAN A. S. MCARTHUR[8]:—We find that people are perfectly satisfied if they know how long it will take them to make a 50 or a 100-mile trip, and the bulk of the passengers are perfectly satisfied if they get there on the scheduled time.

Factors Affecting the Personnel

R. E. PLIMPTON[9]:—What is the age of greatest alertness? Recently, I attended a meeting of the National Safety Council in Chicago. The age of street-car platform-men was particularly under discussion, men well along in years who are handling trolleys in the highly congested districts. A group of the safety experts from the electric railways made the point that very often those men, provided they were examined from time to time and checked up as to their ordinary physical fitness, were better men in spite of their advanced years and had fewer accidents than many of the younger men. One man went so far as to say that the accident-curve for the average employe increased with the first six years; then, for a number of years after that, it tended to go down.

In the motorcoach field, we know that in many cases it is necessary to transfer from one mode of transportation to another. Naturally, if men have served the railway company faithfully, its executives would like to put them over into the new job, and yet I imagine 80 or 90 per cent of them do not. It is hard to simply throw them out into the cold after they have spent the best years of their life working for the company, but that is what officials have to do, because they feel that the motorcoach requires younger and more alert men.

Many of the larger inter-city companies are setting an age limit. They will not hire a man if his age is over 28; but, as time goes on, they must begin to think about an upper limit beyond which they cannot keep those men, many of whom will not progress and get better jobs. It is a serious problem just from the standpoint of safety, which is under discussion, as to how long such men can be kept and just what is in the best interest of the public and of the company.

MR. SCHRAM:—The advent of the one-man car developed a pathetic emergency for the old platform-men. In one company a number of these older men tried to become one-man-car men, but after a week or 10 days they came in and broke down while describing how they could not make change, they could not handle the job, and that they would have to go some place else. I was interested to see in a magazine the figures a university research-board compiled after testing people who had driven 300 miles in one day; 10 to 15 per cent were inefficient after a 300-mile trip.

C. L. VAN AUKEN[10]:—In connection with the speed-control signal, will there not be some difficulties in connection with the maximum speeds allowed by law along

[7] M.S.A.E.—Automotive engineer, Public Service Coordinated Transport, Newark, N. J.

[8] M.S.A.E.—General superintendent, Toronto Transportation Commission, Toronto, Ont., Canada.

[9] M.S.A.E.—Transportation engineer, The White Co., Cleveland.

[10] Vice-president and managing editor, *Electric Traction & Bus Journal*, Chicago.

the roads the vehicles are traveling? When a vehicle runs in two States, there might be a 35-m.p.h. speed-limit in one State and a 45-m.p.h. speed-limit in the other. If the speed-limit signal is set at 45 m.p.h., would that not cause trouble if there were an accident in the State where the limit was 35 m.p.h.?

MR. SCHRAM:—That is true. It is all a matter of development. So far as we have been able to find out, there seems to be a regular stampede to take the speed limit off in practically all these States. But from what I hear from some of the members of the commissions, they feel that it is working out more advantageously.

Maximum Braking Deceleration

THOMAS S. KEMBLE[11]:—Some experiments that I have been connected with indicate that a deceleration of 6 m.p.h. per sec. may be about all that should be provided if we attempt seriously to protect passengers from consequences of too severe braking.

What should constitute the limit of brake deceleration? We set this limit and then relied on the judgment of the driver to apply the brakes more gently under ordinary conditions. A short while ago an extraordinary condition arose in which it was necessary for the driver to apply the brakes fully and immediately. He did avoid an accident, but a man who was standing in the middle of the coach was thrown almost against the dash and flat on his face.

A. W. SCARRATT

Some limit should be applied; but I do not know what the limit is. It undoubtedly is true that the more quickly the driver can stop the motorcoach the greater chances he will take, and the more often he will have to stop it quickly. An investigation relating to experience in connection with specific limits on braking would, I be lieve, be of value. The matter really applies to city operation and to interurban operation almost equally.

MR. SCHRAM:—I agree with Mr. Kemble that if a driver feels he has unlimited braking ability he will take chances and will run at a speed that is detrimental to the vehicle and obnoxious to the passengers and that with a certain limit on his braking ability he will be inclined to keep a constant speed. I know of one line about 9 miles long which operates about 25 large-capacity vehicles and which checks the average speed at least once a month. The brakes are not in the category that Mr. Kemble mentions, but the company's accident record is wonderful.

On certain of the other lines it has received a number of communications from women, particularly about braking. The motorcoach aisle is narrow and the people in it or in the exit or entry who get that unusual braking impulse do not like it, and this is a factor that either helps to make or unmake the desirability of the transportation.

MR. KEMBLE:—Mr. Schram and I agree regarding driver control. I also am greatly pleased to have the speed limit discussed in the way in which it has been treated here. The speed should be limited in the interest of safety, but even with a speed limit, the driver will come up closer to the vehicle ahead in cities and take more chances. In interurban driving he will pass another vehicle when he has a slimmer chance of getting by, if his brakes are too powerful. I believe that it is detrimental to have the brakes too powerful. The ideas of different persons on a specific braking-limit would be of value to the whole industry.

F. C. MCMANUS[12]:—Is the automatic control connected to the drive shaft or to the engine?

MR. SCHRAM:—It has a generator connection.

MR. MCMANUS:—Does the governor ring the bell when the intermediate gears are in use?

MR. SCHRAM:—Yes; it is the engine speed that is controlled. We have had only six signal devices in operation. Of these, four seem to please everyone concerned; with the other two, there is complaint that passengers are annoyed by the signal. We have been considering the possibility of a signal that has a more pleasing sound than that of a buzzer.

MR. MCMANUS:—In the New York City subways they have an automatic air-brake and it gives one a very disquieting feeling while wondering what is happening when a certain noise is heard. There is a sudden blast of air, and not one out of a hundred people knows what causes it. Those who do immediately make a grab for the back or a seat and hang on until the train stops; the others are just thrown about in the car.

Experiences with Heavy Vehicles

A. W. SCARRATT[13]:—We have had experience with motorcoaches and motortrucks. There are so many hazards to contend with on the road that the best brakes one can provide are none too good to take care of emergency conditions. The emergency may not be with the vehicle, but with something ahead of the vehicle. In the development of brakes for our vehicles, we have always tried to provide a brake that would give a rolling stop with the wheels just bordering on a tire slide or skid under maximum-load conditions on dry pavement. That can be a dangerous brake if the pavement is wet; but, ordinarily, one would assume that good road-conditions prevail.

We feel that the use of the brakes is again a matter of driver control, just as all other conditions connected with the operation of the vehicle are the result of driver control. Too much emphasis cannot be placed upon the judgment and intelligence of the driver for a motorcoach. The operation of a heavily loaded passenger-vehicle on some of our crowded highways—and some of those are altogether too narrow for modern traffic conditions—is such that one cannot afford to risk passengers' lives and the large property investment with a man who is at all incapable.

The first thought must be with regard to safety. In connection with this speed-limit control-system and governor control on engines I feel that in motorcoaches the time will come when devices of that kind might be used just for passenger satisfaction, one might say. I think that all of them should be developed so that, in an

(*Concluded on p.* 44)

[11] M.S.A.E.—Consulting engineer, St. Louis.

[12] Jun. S.A.E.—Engineering department, International Motor Co., New York City.

[13] M.S.A.E.—Chief engineer, motor-trucks and coaches, International Harvester Co., Chicago.

Effect *of* Low-Pressure Tires *on* Axle Design

Semi-Annual Meeting Paper

By L. RAY BUCKENDALE[1]

Illustrated with Photographs and Drawings

Development of the tire has caused it to become increasingly more intimately tied up with the design of the heavy-duty vehicle.

Today engineers must recognize the tires as a fundamental starting point in a proposed design.

Introduction of the low-pressure tire caused a vehicle designed for the average permissible load to come hard up against the average 96-in. over-all width limitation.

The dual tire began to take more of the space available for brakes. On the other hand, demands on the brakes were increased because of the higher speeds and the traffic problems that are being encountered in these days.

The distance within the inner tires for a vehicle of 24,000 lb. gross weight is 48 in. Within this distance we must find room for driving mechanism, the springs, the brakes and also clearance for the various parts; and we come out with 34 in. maximum permissible width of frame.

Much greater cooperation is going to be necessary between the engineers responsible for the development of tires, brakes and axles and the vehicle as a whole.

The time has come when arbitrary laws limiting the size and weight of motor-vehicles should be abolished and determination of what may be operated over a given road be left in the hands of engineers employed by the motor-vehicle departments of the various States.

TIRES have always had a profound effect upon the performance of motor-vehicles but this has been an indirect influence. The development of the tire has caused it to become increasingly more intimately tied up with the design of the vehicle. Today, engineers must recognize the tires as a fundamental starting point in a proposed design.

When pneumatic tires appeared and the diameter of wheels decreased, fenders also became common. At this stage the tires began to influence the design of the vehicle. The early pneumatic tires were subject to many ills, some of which were influences of the vehicle itself. Steering geometry, as we now call it, was given attention. As the tires were very small in section and the wheels still relatively large in diameter, there was ample room for any necessary steering linkage. The Ackerman steering-gear, which we know as the steering-knuckle tie-rod and arms, was common and, as the tire and wheel offered no limitations, it was sometimes placed in front of the axle.

Horse-drawn vehicles had established 56 in. as the standard track, and the automobile followed the same standard. The 56-in. track served well for the passenger-car until very recently, but the commercial vehicle quickly began to crowd this limitation, because, as engines of greater horsepower became available, the weight and size of the trucks grew and the tires kept pace; therefore the track was slowly increased to provide room for the other parts of the vehicle and also to provide stability, although, as yet, solid tires were used on trucks.

Legislative Restrictions on Trucks

Because the roads were narrow, the increasing size of the truck attracted the attention of legislators, and a series of limitations on over-all width, length and weight appeared. These limitations did not hamper the design a great deal at first, because there was ample room for tires, wheels, brakes, springs, frame and steering mechanism, as can be seen in a typical chassis of that period, as shown in Fig. 1.

Larger engines, however, had gradually increased the average speed, and speed limits for trucks were established, because the cushioning effect of the solid tire was limited and vibration and road shock were destructive. Use of the truck chassis for a motorcoach brought a demand for easier riding, and pneumatic tires began to appear on the truck. These were larger sizes of the type of tires developed for passenger-cars and, although requiring more space than the solid tires, they left sufficient room for the other elements of the truck or motorcoach.

At this stage of development the commercial vehicle had become conventionalized in many details. The front wheels were steered by means of a cross-tube either in front of or behind the axle, brakes were mounted on the rear axle, the drive was adjacent to the engine, and the cargo was carried on the after portion.

[1] M.S.A.E.—Executive engineer, Timken-Detroit Axle Co., Detroit.

As the percentage of weight carried on the two rear tires was much greater than on the two front tires, the rear tires became much larger than the front tires. This difference in front and rear tires made two spares a necessity, and the larger rear tires were very costly. The general appearance of the rear axle of a typical vehicle of that period is shown in Fig. 2. Enough room was afforded for brakes of any reasonable diameter and for any type of brake-drum.

Dual Pneumatic Tires Caused Difficulties

About this time the idea of using two smaller rear tires, side by side, on the same wheel appeared. Tire capacity in keeping with the weight distribution was thus achieved with six tires, all of the same size, and only one spare tire was necessary. A truck equipped with dual rear pneumatics is shown in Fig. 3.

The fact that the dual tires took up more of the available width and added the complication of the dual wheel brought realization to the tire makers and the axle builders of each other's existence. The pneumatic tire, by its increased cushioning properties, permitted increased average speed of the vehicle, and this speed made greater demands on the brakes. Brakes, however, had been developing independently and had assumed diameters and widths which had no particular relation to the tires. The dual tire, because of its smaller internal diameter and increased width, began to take more of the space available for the brakes, therefore the tendency was to force the brakes to become smaller in diameter and wider. This increase in width of brakes brought the drums closer to the springs. Springs, however, bore a definite relation to the width of the vehicle frame, hence the frames became narrower.

Change in Steering Geometry

In the meantime, two developments were occurring in the passenger-car which were to exert a profound effect on truck and motorcoach design. Front-wheel brakes were introduced experimentally and, after going through a controversial and development period, became accepted as standard. It was therefore logical that, as the limit of space available for rear brakes on trucks and coaches was reached, front-wheel brakes should be adopted for them. But these introduced a new force acting on the front wheels and added another factor that had to be considered in the steering geometry. The distance between the center of tire contact with the road and the axis of the steering-knuckle pivot had to be held within a certain limit because this distance was the lever arm that determined the magnitude of the forces acting on the steering linkage. Fig. 4 shows a typical front axle before the advent of four-wheel brakes. It will be noted that the steering-knuckle pivots are parallel and the length of the lever arm *A* is considerable; also that there is no space limitation on the steering-arm tie-rod, and either a clevis type or a ball type, as shown in Fig. 5, at *A* and *B* respectively, can be used. So the tendency was to design the steering-knuckle pivot closer to the tire and also to incline it from the vertical so as to bring the lever arm within practical limits. This inclination of the steering-knuckle pivot eliminated the clevis-type of steering-arm tie-rod because of the double motion required by the fact that the wheels now rotated about non-parallel axes. The ball-tube type became essential, but the overhang from the ball center to the end of the rod became embarrassing, hence the rod end shown at *C* in Fig. 5 appeared. This permitted the ball center to come closer to the tire and, in addition, was self-adjusting.

Although front axles had not reached any overall limitations fixed by legislation, the prevailing fashion in fenders caused designers to keep the front tread as narrow as possible, with the result that the tires crowded both the brakes and the steering linkage. This was the start of the compromise in steering geometry shown in the front axle in Fig. 6.

Another development that started in the passenger car at this time was the introduction of pneumatic tires of greatly decreased air-pressure and corresponding increase in carcass size for the same carrying capacity. There were several good reasons for this innovation: The low-pressure tires had much better shock-absorbing ability and gave better riding-qualities and in-

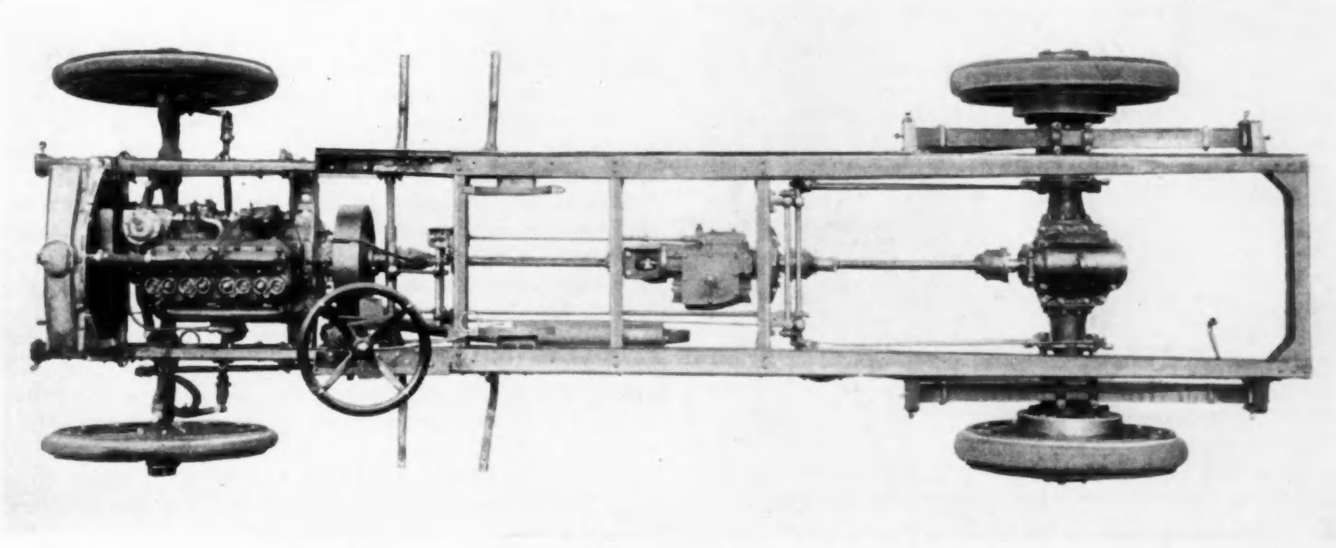


FIG. 1—TYPICAL TRUCK CHASSIS OF THE PERIOD OF SINGLE SOLID TIRES
Ample Space Was Available for Tires, Rims, Brakes, Springs, Frame and Steering Mechanism

creased vehicle life or mileage. These characteristics immediately increased the speed range of the passenger-cars, and, because they were desirable for motorcoaches and motor-trucks, the low-pressure tire soon appeared in the heavy-duty-vehicle problem.

In the meantime, the highway problem was growing and notice was taken of the greater destructiveness of the heavier trucks and coaches to the road surfaces and of complaints by passenger-car drivers that the size of these vehicles was increasing faster than the width of highways increased. The result was further legislation, which was typical in that it was prohibitive and arbitrary rather than flexible and capable of adjustment to varying conditions and to developments in the automotive vehicle. So today each State has laws restricting motor-vehicles as to maximum width, length, total weight, weight per wheel and the like, and the restrictions of hardly any two States are the same. A majority of the States have an over-all width limitation of 96 in., a few have 90 in. and one has 84 in. The tendency also is to limit the gross weight of a four-wheel vehicle to about 24,000 lb.

FIG. 3—TRUCK EQUIPPED WITH DUAL PNEUMATIC TIRES ON THE REAR WHEELS

The Dual Tire, Because of Its Smaller Base Diameter and Increased Width, Took More of the Space Available for Brakes, Forcing the Brakes To Become Smaller in Diameter and Wider

Low-Pressure Tires Cramp Parts

Introduction of the low-pressure tire caused a vehicle designed for the average maximum permissible load to exceed the 84-in. and even the 90-in. over-all limitation and come hard up against the average 96-in. limitation. Those States having less than a 96-in. limitation are restricting the use of the latest automotive equipment, with the result that in those States the larger and more efficient vehicles cannot be used nor can those States enjoy the benefits of the less destructive effect on the surface of highways of the low-pressure tires or of six-wheel vehicles.

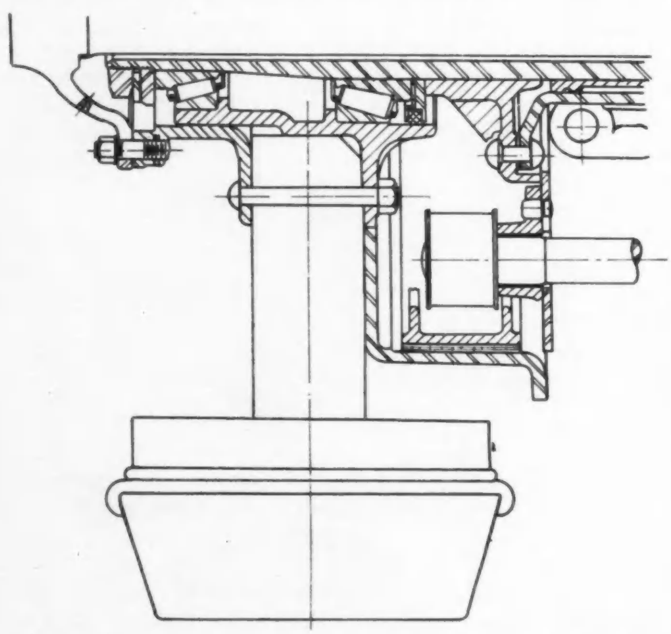


FIG. 2—CROSS-SECTION OF REAR-AXLE END AND WHEEL OF CONVENTIONAL TRUCK USING SINGLE SOLID TIRES

Enough Room Was Afforded for Brakes of Any Reasonable Diameter and for Any Type of Brake-Drum

Let us consider the design of a vehicle to use low-pressure tires and come within the common 96-in. width restriction and the maximum gross weight of 24,000 lb. If we assume that we will use dual tires on the rear wheels and single tires on the front wheels, each tire must carry 4000 lb. This will give us 8000 lb. on the front end and 16,000 lb. on the rear tires. This is the ideal condition, but in practice we find that the size of the engine required will compel shifting the front-axle and rear-axle positions, so that less weight comes on the front and more on the rear. This fact has caused some legislation to fix the minimum on the front at 20 per cent of the gross. Let us assume we get 25 per cent on the front and 75 per cent on the rear. We find that the size of tire required to carry 0.75 x 24,000/4, or 4500 lb., would be 10.50 x 20, with a nominal capacity of 4700 lb. The tire engineer says that when used as duals these tires must be set at a minimum of $12\frac{3}{4}$ in. center to center. The actual width of the tire is approximately 11 in. So, if we position the outer tires at $95\frac{1}{2}$ in., to allow $\frac{1}{2}$-in. spread under load, we have the track of the outer tires $95\frac{1}{2} - 11 = 84\frac{1}{2}$ in. The track of the inner tires is $84\frac{1}{2} - 25\frac{1}{2} = 59$ in. The distance between the inner tires is 59 — 11, or 48 in.

Within this distance of 48 in. we must find room for the driving mechanism, the vehicle springs, the brakes (which legislation requires to be on the wheels) and also clearance for the various parts. Neglecting the brakes for the moment and placing the springs so as to clear the tires, we find that, with a $3\frac{1}{2}$-in. spring, we have a spring center of $40\frac{1}{2}$ in. If we use a 1-in. clip to hold the springs to the axle and allow $\frac{5}{8}$-in. clearance of the frame, we have only 34 in. maximum permissible width of frame.

Brake engineers tell us that to stop a 24,000-lb. load operating at passenger-car speeds will require approximately a $17\frac{1}{4}$-in. effective brake diameter and a width of 5 or $5\frac{1}{2}$-in. The diameter is determined by the practical limit of the pressures that can be applied to the braking surfaces using self-energization or auxiliary

power such as air. These pressures are also limited by the maximum pressure that can be applied to the friction surfaces with expectation of reasonable life.

If we now make up a composite diagram of the conditions we have set up, as in Fig. 7, we shall readily see that many problems are unsolved. We find that when we attempt to place the brake on the wheel it must be nested completely inside the inner tire. With the tire that is available we have a diameter of 20 in, inside the beads. If we subtract the 17¼-in. brake diameter, a radial clearance of only 1⅜ in. remains between the tire and the friction surface of the brake. In this space must be found room for the brake-drum, the tire rim, means for holding the rim to the wheel, and the tire valve and still leave room for the flow of air required to carry off the heat generated by the brakes.

Brakes Present a Real Problem

This brings us face to face with a real problem. If we consider the brake-drum required, we find that the old pressed-type drum shown at *A* in Fig. 8 cannot be used, because a flange is needed to give stiffness and there is no room for a flange. The characteristics required in the drum are maximum resistance to distortion from the high pressure set up by the shoes, maximum ability to absorb and dissipate heat, and maximum resistance to abrasion. Of the many materials used, the cast alloy-iron apparently is emerging as the most successful. A drum cast of this material is shown at *B* in Fig. 8. Castings permit an unlimited variety of shapes. The most desirable form has a series of annular ribs on the exterior surface, as at *C* in Fig. 8. These ribs increase the heat-dissipating ability and the stiffness of the brake-drum for a given mass of iron. It is also desirable to run radial ribs up the back face of the drum, continuing them at right angles to the annular ribs on the periphery. These radial ribs make possible a lighter drum and at the same time give increased turbulence to the air, thereby helping to dissipate the heat. However, if we attempt to put such a drum into a 20-in.-base tire, we find that it will not go; we must compromise on the height

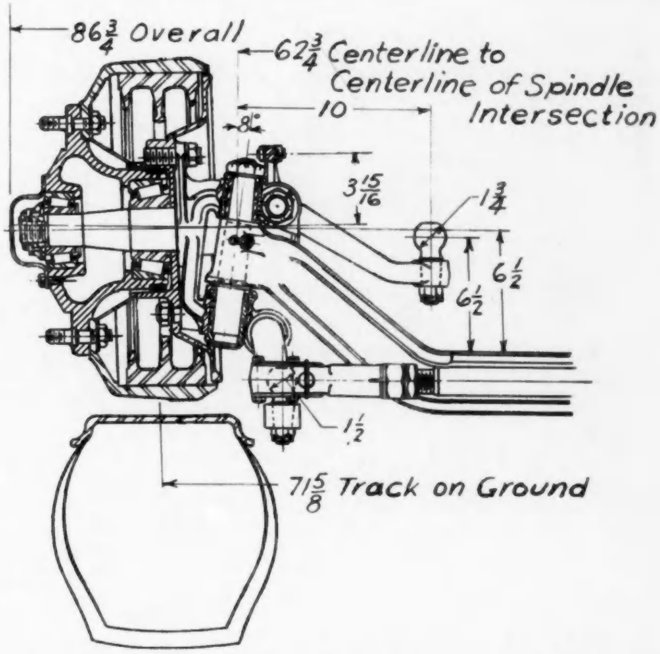


Fig. 6—Front-Axle End for Pneumatic-Tired Vehicles

The Prevailing Fashion in Fenders Caused Vehicle Designers to Keep the Front Tread Narrow. This Crowded the Brakes and the Steering Linkage, and To Hold Within Limits the Distance from the Center of Tire Contact to the Axis of the Steering-Knuckle Pivot, the Pivot Had to Be Inclined Outwardly at the Bottom

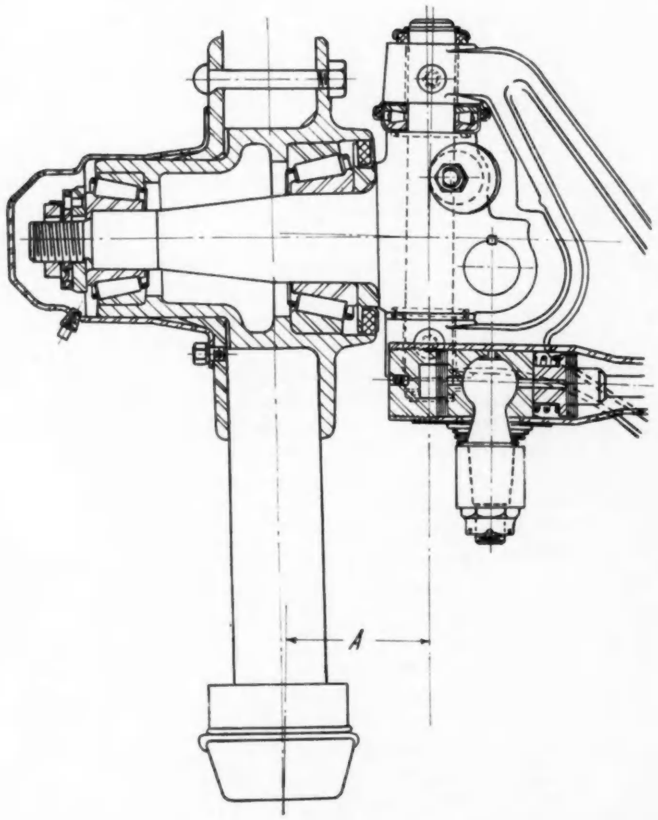


Fig. 4—Typical Front-Axle End Before the Advent of Four-Wheel Brakes

The Steering-Knuckle Pivots Were Vertical and the Length of the Lever Arm *A* Was Considerable; also, the Space for the Steering-Arm Tire-Rod Was Ample

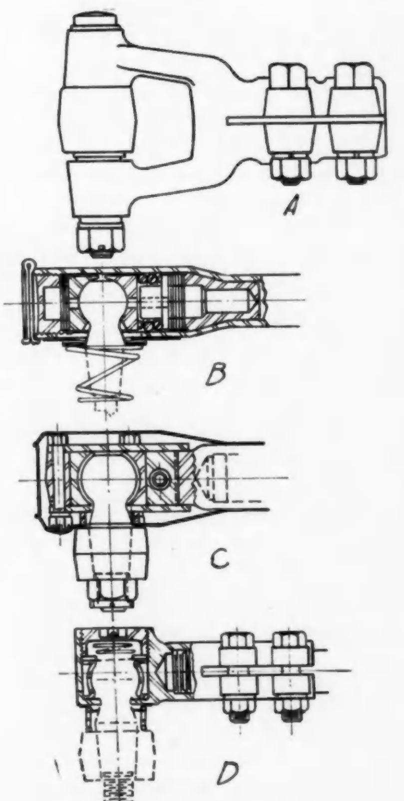


Fig. 5—Progressive Types of Steering-Arm Tie-Rods

A, Clevis Type. *B*, Ball Type, with Long Overhang of the Tube. *C*, Self-Adjusting Ball Type, with Restricted Overhang. *D*, Compact Ball Type Designed To Clear Low-Pressure Tires

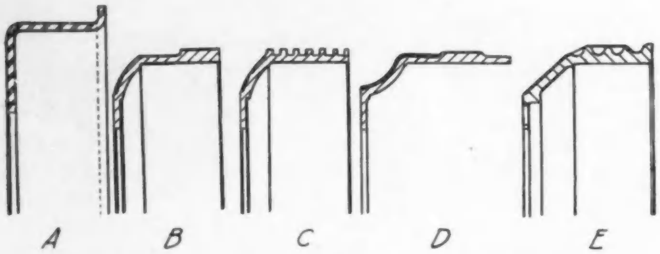


FIG. 8—EARLY AND LATER FORMS OF BRAKE-DRUM FOR HEAVY-DUTY VEHICLES

A, Old Flanged-Type Pressed Drum That Can No Longer Be Used. B, Cast Alloy-Iron Drum That Is Emerging as the Most Successful. C, Annular Ribs Help Dissipate Heat and Increase Stiffness. D, Wide-Faced Drum with Annular Ribs Omitted To Slightly Reduce Outside Diameter. E, Heavy Ribbed-Type Drum That Could Be Used with 22-In.-Base Low-Pressure Tire

of the ribs so that they will merely clear the rims and also must cut grooves or notches to clear the tire valves.

The result of the proximity of the drums to the tires has been to pass heat from the brakes to the tires. This heat added to the heat set up by the action of the tires themselves has caused bead temperatures that are too high for reasonable tire life. The result is that the tire engineer wants to reduce the brake diameter to get the drum away from the tire. If this could be done without increasing the width of the brake face, the result would be higher drum-temperature, because the same amount of heat would have to be dissipated from a smaller surface and the resulting high drum-temperature would radiate more heat to the tire and cancel the benefit from the increased air space. Furthermore, we started with the smallest practical brake diameter, and we cannot increase the width because the over-all width limitation of the vehicle prevents.

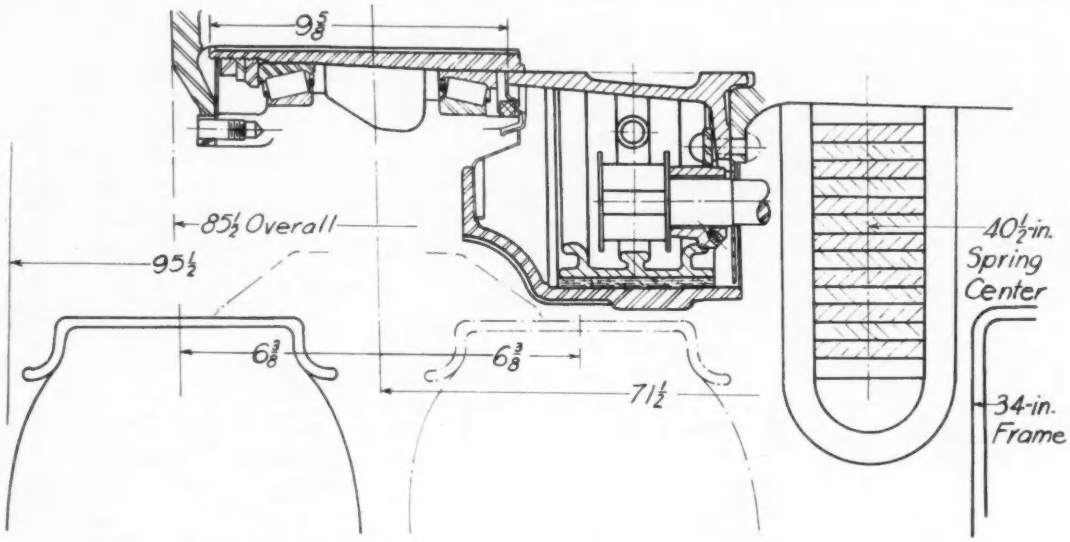


FIG. 7—SECTION OF REAR-AXLE END FOR USE WITH DUAL LOW-PRESSURE TIRES

Note That the Brake Is Entirely Within the Inner Tire, Is Small in Diameter and Has a Wide Brake-Shoe, and Very Little Air Space Is Left Between the Band and the Tire Rim

Wider Chassis Frames Needed

There seems to be only one answer to this problem, and that is to increase the inside diameter of the tire used on vehicles above a certain weight. It is suggested that we consider a 22-in. base for tires of 4000-lb. or greater carrying capacity. Fig. 9 shows the advantage that this 1-in. additional radial clearance of the 22-in.-base tire over the 20-in.-base tire would give. The drum could be made reasonably heavy and ribbed both annularly and radially, and an ample air gap would be provided for heat dissipation as contrasted with Fig. 7.

It will be noticed in Fig. 7 that no clearance has been provided for chains. We have fixed the spring width at 3½ in.; wider springs would permit lower spring-piles and easier riding and reduce the maximum impact on the road. The desirable 5-in. spring would increase the over-all width to 98½ in. The 40½-in. spring center is hardly sufficient to provide lateral stability, especially when the increasing maximum speeds are considered. The 34-in. frame with adequate flanges introduces the problem of trying to find room for the engine required to move the vehicle at the speeds made possible by the low-pressure tires.

Some relief has been offered by the six-wheel vehicle, examples of which are shown in Figs. 10 and 11. Distributing the load on two rear axles has lessened the impact on the roads. This fact has been recognized by the legislatures of some States, which permit greater gross loads on six-wheel vehicles, in some cases 50 per cent more. The result of raising the permissible weight is that the large six-wheeler has come to require the same dual tires as the four-wheeler, and the limitations fixed by the over-all width of 96 in. are even more severe. An attempt has been made in Table 1 to set up the various high-pressure and low-pressure tires, together with their rated capacities. This table also shows the recommended spacing with the actual tire dimensions and the dimensions over-all and between the inner tires to which the various sizes work out. It will be noticed that the 9.00×20 tire is the largest that can be worked out to stay inside of 90 in., and even smaller tires are required to stay inside of the 84-in. over-all limit.

The front axle has had its share of problems introduced by the low-pressure

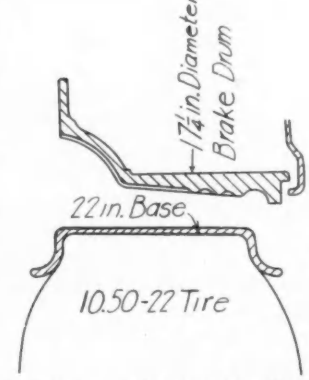


FIG. 9 — CLEARANCE PROVIDED BY 22-IN.-BASE TIRE AND 17¼-IN.-DIAMETER BRAKE-DRUM OF THE TYPE SHOWN AT *E* IN FIG. 8

FIG. 10 (RIGHT)—SIX-WHEEL TRUCK AND TRAILER

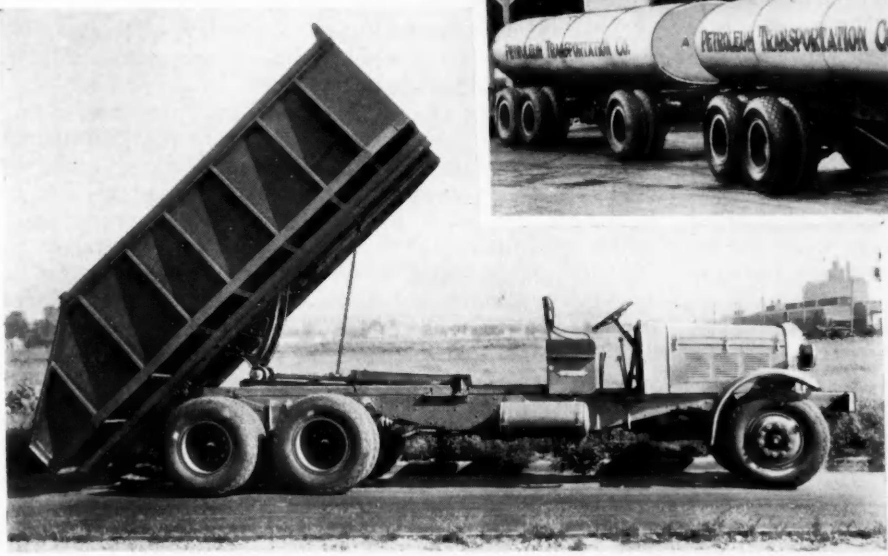


FIG. 11 (BELOW)—SIX-WHEEL DUMP TRUCK FITTED WITH DUAL REAR TIRES

The 10 and 12 Large Pneumatic Tires on These Two Vehicles Distribute the Weight Over a Large Area of Road Surface and Lessen the Impact. However, the Increase in Permissible Weight Carried on Three Axles Has Resulted in the Use of as Large Tires as Are Used on Four-Wheel Vehicles and the Difficulties of Designing the Parts To Come Within an Over-All Width of 96 In. Are Increased

tires, which, because of the much greater carcass dimensions, require more space in the extreme-turn position so as to clear the frame and steering-gear connecting-rod. That means the track of the front wheels must be greatly increased and we promptly run into our old enemy, the 96-in. over-all limit. Because of the necessity of holding within limits the distance from the center of tire contact to the axis of the steering-knuckle pivot, it is necessary to incline the pivot outwardly at the bottom and nest the whole structure inside the tire, as shown in Fig. 6.

The much greater area of contact which the low-pressure tire makes with the ground has made the steering very sensitive to errors in steering geometry, which

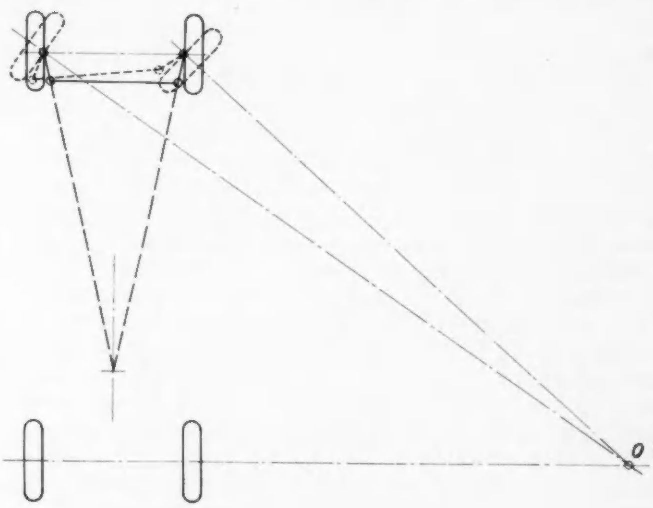


FIG. 12—STEERING GEOMETRY REQUIRED WITH LOW-PRESSURE TIRES TO SECURE TRUE ROLLING ACTION

The Wheels Must Turn About an Axis Which, Projected, Passes Through the Center *O* about Which the Vehicle Is Turning

TABLE 1—DUAL PNEUMATIC TIRE DIMENSIONS[2]

	High-Pressure Tires						Low-Pressure Tires					
Track, In.	Nominal Tire Size[3]	Dual-Tire Spacing, In.	Actual Tire Width, In.	Dimension Over-all Outer Tires, In.	Dimension between Inner Tires, In.	Rated Capacity, Four Tires, Lb.	Nominal Tire Size[3]	Dual-Tire Spacing, In.	Actual Tire Width, In.	Dimension Over-all Outer Tires, In.	Dimension between Inner Tires, In.	Rated Capacity, Four Tires, Lb.
58½	5	7¾	6.05	72¼	44¾	6,800	5.50	7¾	5.67	71 5/16	45 1/16	4,900
63	5	7¾	6.05	76¾	49¼	6,800	6.50	8¼	6.70	78	48	6,600
64¼	6	9	6.90	80¼	48¼	8,800	7.00	9	7.40	80¾	47¾	7,600
							7.50	9	7.75	81	47½	8,400
67½	7	10	8.05	85½	49½	11,200	7.50	10	8.03	85½	49½	8,400
							8.25	10	8.50	86	49	10,200
69½	7	10	8.05	87½	51½	11,200	8.25	10½	8.50	88½	50½	10,200
	8	10½	8.85	88⅞	50⅛	14,400	9.00	10½	9.25	89¼	49¾	13,000
70	8	10½	8.85	89⅜	50⅝	14,400	9.00	10½	9.25	89¾	50¼	13,000
	8	11½	9.25	90¾	49¼	14,400	9.00	11½	9.60	91⅛	48⅞	13,000
	9	11½	9.89	91½	48½	18,000	9.75	11½	10.05	91½	48½	15,600
72¼	9	12¾	10.35	94⅜	50⅛	18,000	9.75	12	10.05	94¼	50¼	15,600
	10	12¾	11.50	96½	48	22,000	10.50	12¾	10.95	96	48½	18,800
72¼	9	12¾	10.35	94⅜	50⅛	20,000	10.50	12¾	10.95	96	48½	20,800
	10	12¾	11.50	96½	48	24,000	12.00[a]	14	12.36	98⅝	45⅞	27,800

[2] Copyrighted by The Timken Detroit Axle Co.
[3] All axles permit 20-in. base to be used, except the last axle, which allows only a 24-in. base.
[a] Assumed dual spacing only.

was not the case with the high-pressure tires. It has become vitally necessary to have true rolling action; that is, the tires must turn about an axis which, projected, passes through the center about which the vehicle is turning, as illustrated in Fig. 12. If this condition is not achieved, undue tread wear occurs; and to achieve this condition is not easy, because the balls of the steering-arm connecting-rod would have to be positioned inside the tires. The last bit of end clearance was achieved by the tie-rod end shown at D in Fig. 5, which permits the ball to come still closer to the tire; but still the correct geometry cannot be achieved, so the only possibility is to remove the steering-knuckle pivot further from the tire. This in turn cuts down the turning angle and, of course, increases the overhang on the spindle, thereby increasing the stress and load on the steering-knuckle structure. This effect tends to cancel the benefit of the low-pressure tire, insofar as its low impact-factor would save the axle structure. However, the advantages of the low-pressure tire outweigh the problems it has created. There is going to be a change in the front-end appearance of the heavy vehicles because of the necessary increase in fender width to cover the larger size of tires and the wider tracks.

The foregoing statement of conditions brings out the fact that much greater cooperation between all of the engineers responsible for the development of tires, brakes, axles and the vehicle as a whole will be necessary if development is to go forward toward the ideal vehicle without burdening the industry with excessive costs resulting from sudden innovations made without considering the vehicle as a whole.

The time has come when the arbitrary laws fixing the dimensions and weights of motor-vehicles should be abolished and the determination of what kinds of vehicle may be operated over a given road be left to engineers employed by the States. These engineers could be guided by a general code that would meet the varying geographical conditions and road limitations. Such a code could be prepared by automotive engineers working with the Bureau of Standards and operating through the departments and commissions provided by the United States for this purpose.

THE DISCUSSION

CHAIRMAN H. W. ALDEN[4]:—The difficulties of the different branches of the automotive industry, particularly the truck and motorcoach branches, are very considerable. We used to have vehicles that weighed 18,000 to 20,000 lb. and traveled at 30 or 35 m.p.h., and we thought that was good performance. Now we have vehicles which ostensibly are made for 39 or 40 passengers and it is not uncommon to crowd 110 persons into them. We equip them with 150 or 160-hp. engines to drive them at 30 or 40 m.p.h. in cities, and when we have to stop them it becomes quite a problem. Twenty-inch-base tires used to provide adequate space to get good braking performance in cities, but it is a serious task now. Safety is the most important factor to consider, and it is increasingly difficult to get adequate four-wheel brakes inside of a 20-in.-base tire to properly control vehicles that weigh 29,000 or 30,000 lb. We have plenty of motorcoaches on the streets carrying 105 or 110 passengers and having a gross weight of 31,000 or 32,000 lb. I think that Mr. Buckendale has carefully brought out in his paper the limitations and the requirements.

Movement for Wider Limit Started

B. J. LEMON[5]:—I think the author has very accurately stated the problem that the axle maker has and the problem which must be worked out between the vehicle builder and the axle maker and the tire supplier to meet the present limitation of vehicle width. The maximum limit of width is 96 in. for a certain number of States, and, as I recollect, only two States have a greater maximum limit. There is no doubt that we need a maximum of 106 or 108 in. in laws governing vehicles that travel on the roads. I think that such a figure is going to be asked for and should be demanded, particularly on superhighways between large cities where there is room to pass these wider vehicles. On secondary country roads it will be difficult to pass a vehicle that is 106 to 108 in. wide.

I think that the movement that has already been started to influence the men who formulate the State laws to recognize the need of these wide vehicles will have its effect within the next year and a half, so that vehicles can be designed and built for large dual tires of the 12-in. size at least, which will require, as Mr. Buckendale stated, a width of 98⅝ in., and probably even more.

The tire maker has perhaps been thought to be promulgating this movement, but I do not think that it can be laid entirely to the tire maker because he has advertised balloon tires. The tire maker was accused of that when the passenger-car balloon tire came, and we know that the tire maker saw the benefits of the passenger-car balloon tire and we believe he sees the advantages of the low-pressure tire for commercial vehicles. He is asked by owners of vehicles in the field to change over vehicles from solid or high-pressure tires to balloon tires, and competition is so keen that he does this wherever he can with present-day vehicles. However, I do not think the movement is being forced; the demand is coming from the operators more than it is coming from the tire people, and what appears to be propaganda by the tire companies is simply an effort to educate the man who owns the vehicle so that, when he demands a change-over, for which the tire people must supply the equipment, he will get a correct one.

Effect on Axle from Change-Over

K. D. SMITH[6]:—We in the tire industry are confronted with the problem of change-over and, in changing over a solid-tired or high-pressure-tired vehicle to low-pressure tires, the tread width is increased and the tires have considerably more traction. Is there any ill effect from increased torque on the present axles, which were designed for either solid tires or high-pressure

[4] M.S.A.E.—Chairman of board, Timken-Detroit Axle Co., Detroit.
[5] M.S.A.E.—Field engineer, United States Rubber Co., Detroit.
[6] M.S.A.E.—Manager, tire construction and design, B. F. Goodrich Rubber Co., Akron, Ohio.

pneumatics, when they are changed over to low-pressure tires?

L. R. BUCKENDALE:—When low-pressure tires are applied to a vehicle designed originally for high-pressure tires, the overhang on the bearing is increased, resulting in an increase in the static bending-load on the structure and so forth. How much that is compensated for by low-pressure-tire impact values I do not know; to some extent it is compensated. That is borne out by the change-overs that have been made.

As to the effect on the driving mechanism, there is some cushioning effect from the tire carcass, but there is a great increase in traction of the tires. The figures available as to these factors are still a matter of debate.

Danger of Recommending Limits

F. C. HORNER[7]:—I want to compliment Mr. Buckendale upon the very comprehensive paper he has presented. I am particularly interested in the last paragraph. On one or two previous occasions I have sounded a note of warning before the meetings of this Society against setting down limitations of the dimensions of motor-vehicles used on the highways. Mr. Lemon mentioned that we are headed now for vehicles more than 100 in. wide. In my opinion 96 in. is, in a great many cases, a thing of the past. I think that also applies to the length and height of motor-vehicles. We are making a great mistake when, even today, we recommend figures for limitation of the dimensions of the motor-vehicles. No one can predict what are going to be the requirements of commercial vehicles of the future, whether we shall need a width of 100 in. or 110 in., a length of 45 ft. and 14-ft. clearance. So I think we are headed for a great deal of trouble if we put into the hands of the State engineers and the legislators of this Country any code that places a limitation on the size of motor-vehicles. Perhaps we must soon come to special toll roads for trucks and motorcoaches; in fact, I think we shall have them within the next four or five years.

This is a day of great progress in certain directions. Already vehicles over 40 ft. long are being operated on the highways. We are right now on the narrow edge of keeping within the law on 96-in. width. We cannot afford to set down limitations now that will very shortly be used against us by State authorities who will say, "You thought that was all right in 1930, and that is what you will have," and then have to battle to have it changed. For that reason I am against the proposed motorcoach code, which contains limitations that I think are absolutely unsound for the requirements of the immediate future and in some respects for today.

CHAIRMAN ALDEN:—That is a very timely warning and I hope that our people who are behind this will not move too rapidly. It is very easy to do so.

DUNCAN P. FORBES[8]:—I was particularly interested in Mr. Buckendale's references to the need of a larger rim size or tire base to give more air circulation around the brake-drum. As I mentioned in another session this morning, a larger brake-drum is required to stop a tire with a 22-in. base than one of 20-in. base, so for braking purposes very little is gained by going to the larger-base tire. We feel that the best results can be obtained by reducing the diameter of the brake-drum and working with brake-lining and brake-drum materials to get a combination that will give satisfactory results on a 16-in. or 16½-in. brake-drum, in that way giving room for the air circulation, which is very important.

Need for Uniform Action

A. J. SCAIFE[9]:—With reference to Mr. Horner's remarks, there is no question that the limitations of today on width are inadequate and that something will have to be done, but just the best way to do it is a question. The legislatures have the whip hand; anything that is done in the matter should be done in complete cooperation with the lawmaking bodies, because they are going to make the laws regardless of what we think or want to do about it.

I believe that our best method would be to bring out the thought, which is one of the reasons for this meeting tonight, whether we ought to go from 96 to 100 or 106 or 110 in., and then use propaganda to obtain the necessary regulation. We want to avoid legislation because it is very undesirable to have limiting dimensions incorporated into law, but it is desirable to have regulations that can be changed from time to time by the State highway engineers through their own organization. We shall probably have to do this work through the National Automobile Chamber of Commerce, which is interested in this subject. There is no doubt that some uniform action should be taken so that each State will take up the question and we shall have a somewhat similar regulation in the various States with reference to the allowable width.

The present very narrow highways will make it difficult to get an increase in the width regulation. That will undoubtedly come as we get wider United States four-lane and six-lane highways, but we probably are a little early for it at present. The question as I see it is, What are we going to do right now to take care of the greater loads, with State laws that are limiting us to 96 in.? Possibly we shall have to put the spring seat on the differential and use a monorail for a frame, with a Sperry gyroscope to balance the load.

CHAIRMAN ALDEN:—Mr. Scaife has not exaggerated the situation very much. When a high load is put on a truck that is only 96 in. over the outside tires, and has a 34-in. frame, a lot of centrifugal force is acting at the turns at the rate that trucks take corners now.

Believes Tire Situation Now Stabilized

JAMES E. HALE[10]:—The complete and effective summary that Mr. Buckendale has prepared is, I believe, a 100-per cent truthful picture of the situation that exists. In the next-to-last paragraph he mentioned the need of greater cooperation of the parts, tire and vehicle makers if costly innovations are to be avoided. Some of the problems involved in the different developments of the motor-vehicle have been under discussion and we know there has been considerable feeling about that. While tire companies apparently have been active in pushing this new line of tires, my judgment is that the present situation will be stable for a long time; so far as I can see, nothing new is likely to come in tire equipment on trucks and motorcoaches for a considerable period. Furthermore, I believe we have chosen a very satisfactory range of sizes to cover the needs of

[7] M.S.A.E.—Assistant to vice-president, General Motors Corp., New York City.

[8] M.S.A.E.—President, Gunite Corp., Rockford, Ill.

[9] M.S.A.E.—Consulting field engineer, White Motor Co., Cleveland.

[10] M.S.A.E.—Development department manager, Firestone Tire & Rubber Co., Akron, Ohio.

the industry. So, with the tire sections, diameters and center spacings rather well agreed upon, I think the truck and coach designers, axle designers, brake manufacturers and wheel makers can all go ahead now feeling that the tire companies are not going to inject any new problem.

One problem that remains is the dissipation of brake heat. Some way must be found to keep down the temperature of the beads. An investigation is under way at present to determine the best and most effective way of dissipating that heat. At the same time the tire companies are trying to arrive at a figure expressed in degrees fahrenheit above which we do not want the beads to be heated.

Practical as Well as Legal Limits

B. B. BACHMAN[11]:—The subject is so large and so much information has been given in the paper that those of us who have been faced with these conditions for some time past find it difficult to add to what Mr. Buckendale has said. I can simply emphasize the importance of all of the details he has brought out with regard to the effect that tire development has had. I am not blaming the tire people for the direction in which their development has led them; that has not been a matter they have deliberately forced upon us. It is true that, in the presentation of a device of this sort through a large commercial organization such as the tire companies maintain, some individuals who may not be fully posted on technical matters have been over-optimistic and over-zealous in advocating applications. Probably each of us can pick out isolated instances of such occurrences. They have been embarrassing and irritating; they have caused us to say things at a time of irritation which calmer consideration would modify to a great degree.

After all of those things are taken into consideration, the fact remains that there is some practical limitation of the width of the vehicle. I am in agreement with the general sentiment that Mr. Horner has voiced; that the placing of stipulated dimensions or limitations is bound to be embarrassing because it is difficult, if not impossible, to predict the trend of development, particularly in the present period. How long this period of development of high-speed heavy-duty vehicles will be and what it will lead us to is almost impossible to predict; but whatever we say with regard to the undesirability of limitations of a legal nature, we must recognize as vehicle designers that there are practical limitations which must be met.

Should Work with Highway Engineers

As Mr. Scaife pointed out, our highways are limited in their widths, even our best highways. Moreover, the vehicles are not operating only on the highway; they must get into places to have the cargoes placed upon them and to deliver their cargoes. That brings us back to a limitation of some sort in width.

We have a maximum weight which requires tires of a certain size. Again, whether or not we are in agreement with the specifications that have been made for tire spacing—and we hope that the latest recommendations on which the Tire and Rim Association is taking action are adequate—the results that will be obtained by the user will determine whether these spacings are right or not. Although Mr. Hale believes that there will be no further modification, I am not sure what the effect of $10\frac{3}{4}$-in. spacing of 10.50 balloon tires will be. I am simply picking that as an illustration.

With regard to the relation of brake-drum size to tire size, it is true that as the tire size is increased the duty on the brake also increases. On the other hand, as Mr. Buckendale pointed out, as the brake size is decreased, the superficial area to dissipate heat and the volume of metal to absorb heat are decreased. You can choose which you believe is the lesser of the two evils; I do not know. It simply illustrates that this problem and the problem of stability on the narrow frames to which we are forced by the limitations, the steering geometry and so forth, are not definitely answerable. We are struggling to find an answer, and in closing I want to emphasize that next-to-the-last paragraph that Mr. Hale pointed out, it will require cooperation of the tire man, the parts maker, and the vehicle maker; and I would like to bring in another one—the engineers of the highway departments.

Full Cooperation Will Solve Problem

CHAIRMAN ALDEN:—I think the S.A.E. members who have to design axles and brakes and the vehicles to use the tires will substantiate me when I say that they bear no grudge against the tire men. If we had not had pneumatic tires we would have had no truck business. The tire companies have given us a pneumatic tire that has been a godsend to the industry. Now we have a combination of elements that do not work very well together, and I am sure that the tire makers are as anxious as the rest of us to solve the problems and have no intention of forcing upon the vehicle designer or the builder anything he does not need. The low-pressure tire is a new device which enables us to carry loads at higher speed and to go in places where trucks could not possibly go a few years ago. So, as Mr. Bachman said, we need complete cooperation. The situation is more serious perhaps than many of the men in this room realize, but I am sure that, with the cooperation of all concerned, we shall come out all right in the end, although in the meantime we may exceed the width limit and some people may be arrested and fined for driving vehicles 100 and 102 in. wide in spite of the law.

[11] M.S.A.E.—Vice-president of engineering, Autocar Co., Ardmore, Pa.

Significance of Tests for Motor Fuels

By Robert E. Wilson[1]

Milwaukee Section Paper — *Illustrated with* Chart

IN THIS PAPER the author discusses the significance of the various tests for motor fuels, particularly in the light of extensive research work along these lines in the past few years by various industrial laboratories and the United States Bureau of Standards. A bibliography of the literature on the subject supplements the paper.

Although a large part of the public still seems to assume that the principal difference to the car user between different grades of gasoline is in mileage per gallon, actually, if today's best and poorest commercial gasolines are compared, the difference in mileage is very small compared with the differences in engine-starting ability, antiknock quality, vapor-locking tendency and liability to injure the engine or the fuel-induction system.

Volatility is generally believed to be the most important property of a motor fuel, but recent research has demonstrated that the 10-per cent point on the American Society for Testing Materials distillation curve is the best measure of the ease of starting in cold weather and of the danger of vapor lock, while the 90-per cent point is the best measure of the ease of uniform distribution and lack of crankcase-oil dilution in an engine after it has warmed up. Other intermediate points are of some importance in determining the ease of acceleration, especially while the engine is being warmed up; but, in general, suitable limits on the 10, 50 and 90-per cent points of a fuel will, the author asserts, assure good performance under all conditions so far as fuel volatility is concerned. The 10-per cent point especially must be closely controlled to assure easy starting without too much danger from vapor lock.

Antiknock quality is today a property of almost equal importance, from the standpoint of performance, with volatility of the fuel in its various aspects. Actual engine tests under carefully controlled conditions are as yet the only reliable measure of antiknock value. Difficulties in developing a standard engine-test are discussed in detail.

Sulphur content, gum content, and freedom from corrosive substances are each of importance in determining whether a gasoline can be used steadily without corroding or clogging the fuel system or the engine. Other properties of gasoline have little or no influence on the performance of a motor fuel, except that variations in viscosity or gravity may necessitate the readjustment of the carbureter.

High volatility and antiknock value and low sulphur and gum content cost money to obtain, but frequently the automotive engineer, by correct design, can decrease the need for too-rigid specifications on all those points. Of special importance in this connection are (*a*) more care in designing to prevent overheating of fuel lines, vacuum tank and other parts of the fuel system, thus permitting the use of valuable fuels without danger of vapor lock; (*b*) prevention of crankcase corrosion, thus raising the permissible limits for sulphur by eliminating the condensation of water in engines and crankcases; and (*c*) more uniform cooling of engines, especially aircraft engines, to reduce the tendency of hydrocarbon fuels to detonate.

EIGHT or ten years ago there was no more certain way of starting an acrimonious discussion than to mention the question of gasoline end-point in the joint presence of an oil man and an automotive engineer. Such discussions were productive of far more heat than light, because the background of facts was inadequate, but they did stimulate research by the larger laboratories in both industries and eventually resulted in both industries financing the Cooperative Fuel-Research program which has been carried out by the Bureau of Standards under the guidance of a joint steering committee.

As a result, the last six or eight years have been characterized by careful and intelligent research in many different laboratories directed toward determining just what tests and specifications are necessary to assure satisfactory performance of motor fuels under different conditions. The results they have reported in detail now make it possible to discuss with intelligence and a reasonable degree of certainty the real significance of all of the more important tests for motor gasoline and to outline the requirements for certain other tests not yet standardized.

While a large portion of the public still clings to the belief that the principal difference between different grades of gasoline is in economy or mileage, it is a fact that the differences in the mileage are very small compared with the differences in the performance of the fuels and their possible injury of the engine or the fuel-induction system. The following sections, therefore, discuss in considerable detail the various tests for motor fuel from the standpoint of just what they indicate as to performance, economy, and possible injury of the engine or induction system. An effort is made to summarize and give references to the more important recent research work on the various subjects. A study of these many rather highly technical papers emphasizes the need for such a summary of the practical significance of these researches.

Tests for Volatility

Volatility is generally believed to be the most important property of a motor fuel. Under given engine conditions the ease of starting, the rapidity of acceleration, and the likelihood of trouble from crankcase-oil dilution, vapor-lock and loss by evaporation, all depend almost entirely upon the volatility or vapor pressure of some portion of the fuel. In view of this fact, it is rather surprising that there is no generally accepted

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test which measures directly the volatility of the fuel under conditions similar to those prevailing in service.

The routine measurement of volatility has been carried out almost exclusively by the distillation of a 100-cc. sample of gasoline according to the American Society for Testing Materials method No. D 86-27. In this method of batch distillation, which involves a certain degree of fractionation, the determination of the initial boiling-point does not bear any close relationship to the vapor pressure of the fuel; first, because it neglects from 1 to 5 per cent of very light hyrocarbons that fail to show up as liquid in the condenser; second, because the thermometer is placed in the neck of the flask and not in the body of liquid; and, third, because the thermometer has a pronounced lag at this point in the distillation (10)[2].

As the distillation proceeds, the character of the residue in the flask becomes increasingly different in composition from anything produced under engine conditions because, in the batch distillation test, the lighter products are progressively and rather completely removed from the flask as the distillation proceeds, whereas in the carbureter and manifold of an engine the gasoline is introduced into a flowing stream of air where it vaporizes continuously, at lower temperatures, and all the vaporized constituents remain in contact with the unvaporized residue and greatly affect its composition and vapor pressure. The end-point of the A.S.T.M. distillation is nearly 300 deg. fahr. higher than, and bears no definite relation to, the temperature of complete vaporization in the manifold.

In view of these facts it seems desirable to develop continuous-distillation methods that would more closely approximate the conditions of service, and this has been attempted by a large number of investigators (1 to 15). It has been found, however, that to carry out enough such tests to give a complete picture of the volatility of the gasoline is enormously more difficult and time-consuming than to carry out the well-standardized and generally accepted A.S.T.M. distillation test. Furthermore, it is surprisingly difficult, especially at the lower temperatures, to obtain equilibrium in any continuous air-distillation method (15). As a result, the effort of most workers in this field during the last few years has been to correlate the results of these theoretically more sound but more difficult tests with the results obtained by the ordinary A.S.T.M. distillation. Fortunately, these efforts have been crowned with a rather surprising degree of success, and, while the fundamental weaknesses of the A.S.T.M. distillation test are fully realized, satisfactory empirical relationships have been developed between the important volatility characteristics of the motor fuel and certain points on the A.S.T.M. distillation curve, as will later appear.

As previously intimated, volatility is not a single property, but the volatility of different portions of the fuel is of importance for different reasons, which will be discussed separately.

Ease of Starting.—In starting a cold automobile engine, the almost universal practice is to use the choke, which is simply a device for greatly increasing the ratio of gasoline to air so as to vaporize enough gasoline to furnish an explosive mixture in the engine. Obviously, the greater the ratio of liquid gasoline to air supplied, the smaller is the proportion of the gasoline that must be vaporized to furnish an explosive mixture. However, excessive choking means waste of fuel and excessive dilution of the crankcase oil and is therefore to be avoided.

Indications of Ease of Starting

Extensive work at the Bureau of Standards (10) has shown that the 5-per cent point, corrected for loss[3] in an A.S.T.M. distillation is about the best indication of the ability of a gasoline to start an engine easily at extremely low temperatures when the choke is pulled out to the maximum extent to give about a 1:1 mixture, and that the controlling point on the A.S.T.M. curve goes up to about the 15-per cent point for 2:1 mixtures under moderate weather conditions. For practical purposes, if the 10-per cent point of a motor fuel is properly specified, there is little chance that the 5 or 15-per cent points can be far out of line, because the two are necessarily tied together rather closely; and it is therefore generally agreed that the 10-per cent point on the A.S.T.M. distillation curve, corrected for loss, is the best available indication of the general ease of starting an engine on a given gasoline. The Government specifications require 10 per cent at 176 deg. fahr., not corrected for loss; but most present gasolines have 10 per cent off at 158 deg. fahr. or lower to assure easy starting down to 0 deg. fahr. (17). The 10-per cent temperatures corrected for loss would average about 12 deg. fahr. lower. Dickinson states (18) that the 10-per cent point corrected for loss should be 140 deg. fahr. to start an engine readily at 0 deg. fahr.

Vapor-Locking Tendency and Evaporation Loss.—More effective recovery of casing-head gasoline and similar light ends from refinery gases in recent years has greatly increased the amount of light ends available for, and utilized in, commercial motor gasoline. This has resulted in a great improvement in the ease of starting with modern commercial gasolines. However, the presence of large percentages of light ends in gasoline is not an unmixed blessing, because it tends to increase vapor lock and evaporation loss.

Gas or vapor lock is due to the formation of bubbles or slugs of vapor in the fuel system or the carbureter jet, which decreases the amount of fuel supply and thus starves the engine. This tendency is increased by applying heat to the manifold very close to the carbureter and the general tendency toward higher temperatures under the hood. Running the gasoline feed-line near to the exhaust pipe also tends to increase this trouble. Some recent cars will not run smoothly on any gasoline in congested traffic in hot weather, because intermittent

[2] Numerals given thus in parentheses in the text are references to correspondingly numbered investigators and their papers listed in the bibliography on the subject printed at the end of this paper.

[3] The matter of correction for loss probably needs explanation. In the ordinary A.S.T.M. test, the percentage distilled off can be conveniently determined only by measuring the liquid collected in the receiver; but in almost any modern gasoline amounts of light ends, generally varying from 1 to 4 per cent, fail to condense at the temperature employed and are determined by adding the residue in the flask to the contents of the distillate receiver at the end of the distillation test and then subtracting this quantity from the 100 cc. originally charged. The difference is reported as distillation loss. It is obvious that these unrecovered light ends come off during the very early stages of the distillation and also that, even though they do not show up in the distillate receiver, they are nevertheless very effective in increasing the ease of starting. Therefore, in making accurate comparisons of different gasolines, it is necessary to add the distillation loss to the lower end of the distillation curve where it belongs. This simply means adding the loss, say 2 per cent, to each observed percentage of distillate in the receiver before plotting or reporting the results. Confusion would be decreased and the A.S.T.M. test would fulfill its function better if the method specified correcting all results for distillation loss. Fig. 1 shows an A.S.T.M. distillation curve before and after correcting for loss. The term "per cent evaporated" is frequently used for distillation results that have been corrected for loss.

running and idling causes local overheating of some part of the fuel system.

The evaporation loss of gasoline is not solely a problem of the refiner and marketer of gasoline, because, with very volatile gasolines, a serious evaporation loss from the gasoline tank of a car is likely to occur in hot weather, especially if the tank is placed so that it receives heat from the exhaust when the car is not moving. When the temperature under the hood is high, a serious evaporation loss is also likely to occur from the vacuum tank of cars equipped with such tanks. While the boiling off the light ends in this manner may tend to decrease vapor-lock troubles as compared with a gasoline-pump system, it represents a waste that should be avoided if possible. However, under present conditions of overproduction, the petroleum industry is grateful for the extensive use of vacuum tanks and exhaust-heated gasoline tanks and lines!

Determining Factor in Vapor Lock

Recent work at the Bureau of Standards (19) and elsewhere has shown that the gas-free vapor pressure of a motor fuel, or, to put it in another way, the temperature at which boiling begins under the pressure prevailing in the fuel-induction system, is the determining factor in causing vapor lock as well as evaporation loss.

For reasons previously stated, the initial boiling-point in the A.S.T.M. test does not indicate the temperature at which boiling in the lines, or vapor lock, is likely to occur, but the Bureau of Standards has found (19) that the actual temperature of the liquid in the A.S.T.M. flask when boiling just begins and, hence, the temperatures at which vapor lock will begin to occur at atmospheric pressure, is almost identical with the 10-per cent point corrected for loss on the ordinary A.S.T.M. distillation[4]. This is also a measure of the initial evaporating tendency; so, from the point of view of the three factors—ease of starting, vapor lock, and evaporation loss—the A.S.T.M. 10-per cent point corrected for loss is the critical figure. (See Fig. 1.) Both the danger of vapor lock and the desirability of avoiding excessive evaporation tend to fix a minimum desirable temperature for the 10-per cent point. Present Government specifications provide that the 10-per cent point, not corrected for loss, shall not be below 122 deg. fahr., but allow a small reduction in this minimum if the distillation loss is less than 4 per cent. However, the specification also states that for certain special purposes, such as tropical storage, this lower limit may be raised to 140 deg. fahr. with the same credit for low distillation-loss.

While the present Government specifications allow an ample range between 122 deg. fahr. and the maximum limit of 176 deg. fahr. for the 10-per cent point, it has already been pointed out that most present commercial gasolines have a 10-per cent point below 158 deg. fahr., with the 10-per cent point *corrected for loss* generally lying between 135 and 150 deg. fahr., which temperatures are necessary to give easy starting around 0 deg. fahr. The Bureau of Standards results on vapor lock indicate that any such gasoline is likely to cause vapor lock if the gasoline is heated above 140 deg. fahr. before it is metered by the carbureter. Recent measurements on two or three makes of car known to be subject to vapor lock have revealed temperatures well above this, as high as 165 deg. fahr. at the carbureter and 270 deg. fahr. at one point in the gas line.

The foregoing facts indicate clearly that the 10-per cent point corrected for loss must be held within a very narrow margin, say 125 to 150 deg. fahr., to obtain satisfactory performance under all reasonable driving conditions, and also indicate that even with such narrow limits some cars will have trouble with vapor lock under certain conditions. On this point the petroleum industry will have to ask the automotive engineers to design the fuel system so that the gasoline temperature before carburetion will never exceed 125 to 130 deg. fahr. The petroleum refiners, on the other hand, must exclude all but traces of propane and other very wild constituents and keep the 10-per cent point of the gasoline in the narrow range just specified.

Uniform Distribution and Prevention of Crankcase-Oil Dilution.—In the early days of research on vaporization of gasoline, it was sometimes assumed that gasoline must be completely vaporized in order to secure uniform distribution and prevent excessive waste of fuel. Research has indicated, however, that this is not true and that, if a fairly large proportion of a gasoline is vaporized and the remainder is thoroughly atomized, distribution and fuel economy are practically as good as though the gasoline were completely vaporized, while the volumetric efficiency is better and the tendency to detonate much less than if the manifold were heated enough hotter to completely vaporize the gasoline.

Although it is thus generally agreed that a gasoline does not have to be completely vaporized in order to function effectively, it has nevertheless been demonstrated that the temperature of complete vaporization, or dew-point, of a definite mixture of air and gasoline, say 12:1, is the controlling factor in determining the amount of fuel that will dissolve in the crankcase oil under given weather and engine-operating conditions. This dilution of the crankcase oil does not occur to an extent sufficient to appreciably affect fuel consumption, but under winter conditions it may thin out the lubricant so badly as to give excessive oil consumption and even cause wear or injury of the engine. The tendency to cause dilution probably constitutes the most important present limitation on the upper boiling-range of a motor fuel (46). It is also true that if there is too much high-boiling material in the gasoline its distribution characteristics are likely to be inferior, causing both a loss of power and diminished economy; but few commercial gasolines of today have enough high-boiling constituents to appreciably affect the mileage they will give under ordinary operating conditions. Thus, while the volatility of the heavier portion of the gasoline must be reasonable, it is distinctly less important than is that of the lighter portion, for the reasons already discussed.

It was pointed out (1) long ago that the end-point of the A.S.T.M. distillation has no real relation to the temperature of complete vaporization or dew-point of the gasoline, and this fact is now generally conceded, although it seems impossible to keep the trade or even well-informed technologists from talking in terms of end-point as a convenient rough description of a gasoline.

A number of methods have been developed for deter-

[4] In a paper not yet published but presented before the Society of Automotive Engineers by Bridgeman and Aldrich in January, 1930, it was stated that benzol blends or casinghead blends containing more than traces of propane are exceptions to this rule. If there is any substantial amount of propane present, the vapor-lock temperature may be substantially lower than the 10-per cent point.

mining the temperature of complete vaporization or dew-point of a gasoline-air mixture (1 to 5, 11), and the more recent ones are undoubtedly quite accurate and fairly rapid if suitable apparatus is available. However, the net result of all the work that has been done with these methods is to indicate that for all practical purposes the 90-per cent point of a gasoline, by the ordinary A.S.T.M. distillation corrected for loss, is a reliable indication of the dew-point of a given gasoline-air mixture.

Bridgeman (12) gives the following relationship, rearranged to use degrees fahrenheit, between the corrected A.S.T.M. 90-per cent points and the dew-point of 12:1 mixture:

$$\text{Dew-Point (12:1 mixture)} = \frac{\text{A.S.T.M. 90-per cent point, corrected, in deg. fahr.}}{1.399} - 131$$

A later paper by the same author (16) indicates that for some fuels the dew-point may be determined with slightly greater accuracy by a more complicated equation involving the slope of the distillation curve, while Brown (11, 15) recommends the following equation, which generally gives a dew-point about 2 deg. fahr. lower than that from Bridgeman's equation:

$$\text{Dew-Point (12:1 mixture)} = 5/7 \times (\text{A.S.T.M. 90-per cent point, corrected, in deg. fahr.} - 186 \text{ deg.})$$

Whichever equation is the more accurate, it appears that the specification of the A.S.T.M. 90-per cent point is adequate to control the dew-point and the tendency to cause crankcase-oil dilution. The present Government specification on this point is 392 deg. fahr. for regular motor gasoline and 356 deg. fahr. for a special high-volatility gasoline. This corresponds to dew-points of a 12:1 mixture of about 148 and 122 deg. fahr. respectively.

Ease of Acceleration.—While the foregoing results indicate clearly that the 10-per cent point and the 90-per cent point in the A.S.T.M. distillation test are important criteria of gasoline quality, there has been considerable doubt and discussion as to whether any of the intermediate points had any appreciable bearing on performance. Earlier work had shown that these intermediate points had no appreciable bearing on the ease of starting, vapor lock, or crankcase-oil dilution, but it was felt that they might have an effect on the rapidity of acceleration at low engine temperatures. The Bureau of Standards has therefore carried out a very difficult and extensive line of investigations to settle this point, and its results (21) and those of Brown (22) do indicate that these intermediate constituents between 15 and 60 per cent vaporized are of importance under certain engine and weather conditions, though the differences are not large for gasolines of the same 10 and 90-per cent points.

The direct determination of the intermediate amounts vaporized under conditions like those in the manifold is very difficult, especially at the lower temperature (15). Bridgeman (12 and 13) has developed some rather simple empirical relationships between the percentage vaporized in continuous air-distillation simulating manifold conditions and the A.S.T.M. distillation test. His later work (16) and that of Brown (15) indicate that this empirical relationship is not satisfactory for special types of gasoline, such as aviation gasoline or natural gasoline, which have rather markedly different shapes of distillation curve, but such conversions can be made by more complicated formulas (16) involving the slope of the distillation curve. These relationships have been used in calculating the air-distillation curves for the average 1929 gasoline in Fig. 1.

While the relationship between these intermediate percentages vaporized and any single point on the A.S.T.M. curve is not as definite as for the points previously considered, the consensus of present opinion is that a specification of the A.S.T.M. 50-per cent point which is not so rigid as to curtail the yield of gasoline obtainable from a well-balanced refinery but is strict enough to prevent the use of freak blends is desirable in order to assure reasonably good acceleration and distribution characteristics at moderate temperatures.

If the 10, 50 and 90-per cent points of the gasoline are properly specified, in the light of the foregoing discussion, there seems to be no need of any other specification to assure an entirely satisfactory product as far as volatility is concerned. The refiners have no particular objection to a reasonable end-point specification, but the end-point seems to have no real bearing on performance and hence no proper place in specifications.

Description of Curves on Fig. 1

Curve 1 is the ordinary A.S.T.M. distillation curve for the average grade of gasoline marketed in the United States during the summer of 1929 (17). Curve 2 is the same curve corrected by adding to the lower end of the curve the average distillation loss, amounting to about $2\frac{1}{2}$ per cent. Curve 3 is a calculated continuous-distillation curve for the same fuel in the absence of

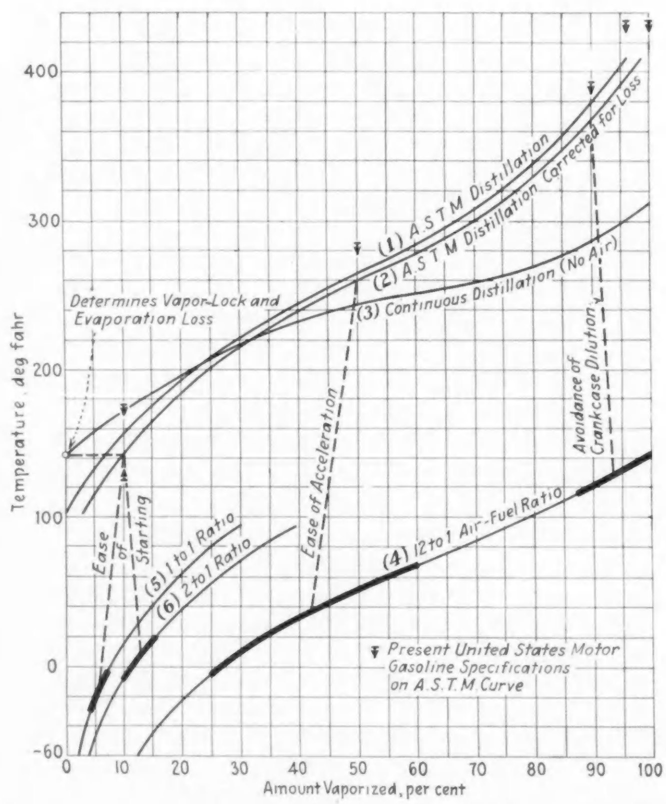

Fig. 1—Various Distillation Curves for Average 1929 Commercial Gasoline, Showing Their Bearing on Performance

air or steam. Curve 4 is the air-distillation curve for a mixture of 12 parts of air with 1 part of this same gasoline, calculated from Bridgeman's equation (16). It shows what would take place in a typical manifold at different temperatures, assuming equilibrium to be attained. Curve 5 is a calculated curve (from Bridgeman) for a 1:1 air-fuel ratio as obtained by severe choking to give starting below 0 deg. fahr. Curve 6 is a similar curve for a 2:1 ratio representing less severe choking for starting at temperatures around or somewhat above 0 deg. fahr. Note that 5 per cent vaporized in a 1:1 mixture or 10 per cent vaporized in a 2:1 mixtures gives a 20:1 air-vapor mixture, which is about what is required for starting.

The heavy dotted lines indicate relationships which have been established between significant points on the continuous or air-distillation curves and the controlling points on the A.S.T.M. distillation curve corrected for loss.

Tests for Antiknock Value

With the gradual increase of compression pressures, the antiknock value of a gasoline has become virtually as important as its volatility. Knocking is not only distinctly unpleasant but results in a loss of power and may actually damage the engine if it becomes severe. The knocking tendency of present commercial gasolines constitutes the present limitation upon the compression ratio of automobile engines, which would otherwise be much higher for the sake of increased power and economy. Therefore it is very important for the further development of gasoline engines that the average antiknock value of commercial and aviation gasoline be increased and also that special fuels of uniformly high antiknock value be made generally available.

In spite of the general recognition of the importance of measuring the antiknock properties of a gasoline, it is unfortunately true that there is today no generally recognized standard method for making such a test. While this present situation is unfortunate, it is not surprising in view of the extreme complexity of the problem and the fact that it is only in the last 12 or 15 years that anyone appreciated that different gasolines are markedly different in their tendency to detonate and only about seven years since the knock rating of gasoline became a matter of commercial importance. Under the circumstances it seems worthwhile to outline the difficulties to be overcome and the progress that has been made to date.

At the outset it may be said that, while many have attempted to estimate the antiknock value of gasoline by chemical analysis of its constituents, by the so-called aniline point (the temperature at which one volume of aniline just dissolves an equal volume of gasoline), by tests in bombs or by the measurement of oxidation rates, and so forth, it can be stated without question that at present none of these methods can be relied upon to give even an approximate indication of the relative antiknock value of a wide variety of gasolines. The one method of testing that must still be relied upon is to run the fuel in an engine under conditions that will cause some detonation.

When the antiknock value of a gasoline has been determined in an engine, the first serious question that arises is how to express the results. A considerable amount of work has been done with variable-compression engines in which the compression ratio of the engine running on a given gasoline is increased up to a point at which knocking begins, or reaches a definite low intensity; and these compression ratios, which are frequently referred to as the *highest useful compression-ratios* (H.U.C.R.), are used as a measuring scale for antiknock value. Somewhat similar results can be obtained by using a conventional high-compression engine and varying and recording the throttle opening, manifold pressure, power output or spark advance obtainable before a definite degree of knocking is encountered.

The objection to all such methods of recording antiknock value is the fact that they depend, first, upon the particular engine used and, second, upon the precise condition of the engine at the moment the test is made. The first difficulty can be largely overcome by the difficult but not impossible expedient of having everyone use exactly the same design of test engine. Even under these conditions small differences in the precise setting of the valves, the momentary condition of valves and rings, spark-plugs, carbon deposits, cooling surfaces and so on have a marked effect on the results obtainable, so that the method at best is not satisfactory for making accurate and reproducible determinations of antiknock value.

Largely to avoid these difficulties due to changing engine-conditions, the general practice in most laboratories today is to determine antiknock by some method of matching an unknown sample with a known standard fuel, the test being made in the same engine within a few minutes of the same time, the fuels frequently being alternated so as to eliminate the effect of changing engine-conditions. This solution might seem to be a simple and happy one but, unfortunately, it has two fundamental difficulties which have not yet been entirely overcome. The first is the question of what standard fuel to use. The workers in most engine laboratories have solved this to their own satisfaction by keeping a large stock of a standard gasoline which is supposed to have a stable antiknock value, but this does not solve the problem of an ultimate standard with which other standards can be compared in any laboratory. Edgar (32) has proposed the use of varying mixtures of two pure chemical compounds; one normal heptane, which has a very pronounced knocking tendency, and the other iso-octane, which has good antiknock properties. The scarcity and high cost of these fuels probably is one factor that has prevented their general adoption, although they are used as ultimate standards in several laboratories. Heptane seems to be about the only available pure hydrocarbon that knocks badly, but for the scarcer iso-octane, as the component of high antiknock value, others (33 and 34) have recommended the substitution of pure benzol, toluol or cyclohexane.

A considerable number of companies compare their unknown fuels with blends of a straight-run gasoline of fairly high knocking tendency and different amounts of benzol, and terms such as "40-per cent benzol equivalent" are bruited about as if they had some definite meaning, whereas their significance necessarily depends entirely on the base gasoline with which the benzol has been blended, and no such gasoline has ever been generally standardized. Sometimes the base gasoline is stated to be "straight-run Pennsylvania gasoline," but in even this case there are marked differences between Pennsylvania gasolines due to differences in boiling range or variations in the composition of the crude.

As a matter of fact, the only generally recognized and widely used antiknock standard available today is the Ethyl-gasoline standard, which is based on samples of fuel sent out by the Ethyl Gasoline Corp. laboratories and duplicated by a large number of oil companies. Of course, this single standard does not provide a satisfactory rating *scale* for the measurement of the knocking tendency of an unknown gasoline, although unknown gasolines can be and frequently are rated in terms of the number of cubic centimeters of tetrethyl lead required to bring them up to match the Ethyl standard.

While this method of rating is useful and entirely satisfactory for those who are marketing ethyl gasoline and who merely desire to know how much lead is required to bring a given sample up to standard, it is not an entirely satisfactory method of measurement, because two gasolines may require the same amount of lead to bring them up to Ethyl standard and yet differ somewhat in their knocking tendency, or vice versa. Furthermore, this method cannot readily be used for measuring the antiknock value of certain special blending stocks the antiknock values of which exceed the Ethyl standard. The obvious possibility of testing such blending stocks by adding more tetraethyl lead to the Ethyl standard is not a solution of the problem, because the antiknock effect of lead added to the Ethyl standard varies greatly with the amount of lead already present in the standard; the absolute antiknock value of each additional cubic centimeter of lead drops off rapidly as the total amount of lead present increases.

The other difficulty in determining antiknock value by matching samples is the fact that two samples that match exactly under one set of engine conditions may not match under another set of engine conditions (35). It is well known that all gasolines knock worse at higher compressions or higher engine temperatures, but, unfortunately, the rate of change differs for different kinds of gasoline. For example, a given gasoline containing tetraethyl lead which just matches a given benzol blend tested at moderate temperatures will, in general, be much better than the same benzol blend tested at higher engine temperatures. This explains the necessity of testing gasolines at temperatures and compression ratios similar to those encountered in service and emphasizes the fact that antiknock testing for fuels to be used in an air-cooled aviation engine should not be carried out in the ordinary water-cooled test engine.

In matching two fuels, the question also arises whether two gasolines should be matched against each other at the same carbureter setting, the same mixture ratio, or at the mixture ratio giving maximum detonation. Each of these methods of testing is likely to give somewhat different results, especially if the two fuels are widely different in composition. This is one objection to the use of benzol blends containing large amounts of benzol as an antiknock standard.

Other factors, such as humidity, spark intensity, kind of spark-plug, engine speed, and so on, may and probably generally do have some effect on the results obtained when attempting to match two fuels of quite different type. It is obvious that, until the exact effect of these factors can be determined and an intelligent selection made of the best combination of all these variables, it would be unwise to standardize a knock-testing method, as this would probably tie both the petroleum and automobile industries to a testing method that might not give a good measure of the real antiknock value of different types of fuel and that would inevitably retard the development and ultimate adoption of a thoroughly satisfactory method of knock-testing.

Recognizing the necessity for a thorough study of all these factors, a Subcommittee on Methods of Measuring Detonation of the Cooperative Fuel-Research Steering Committee has been working for about two years with the very active cooperation of the Bureau of Standards. The work to date has included surveys of the antiknock values of the different fuels available (36), surveys and comparison of different testing methods (37 and 38), and the design of an improved antiknock test-engine which has been built by the Waukesha Motor Co. and is now being used for research on knock-testing in about eight different laboratories (39). A progress report made by the Bureau of Standards[5] at the January, 1930, meeting of the Society of Automotive Engineers in Detroit indicates that the survey of the effect of all important variables on knock-testing is well under way. Boyd and others (34) have just reported a survey of available standard fuels, and Brown (47) has recently announced the adoption of a standard testing technique. In view of all this activity, I believe we may confidently expect a satisfactory standardized method of determining antiknock, at least for automobile fuels, within another year. Meanwhile, most oil refiners are closely watching and holding substantially constant the antiknock value of both their regular and their premium grades of fuel.

Loss of Antiknock Value in Storage

For most straight-run and liquid-phase cracked gasolines with or without the addition of ethyl fluid, the antiknock value is substantially constant over any reasonable period of storage provided excessive evaporation losses are avoided. Our laboratory and others (30) have recently found, however, that certain gasolines of high anti-knock value, and especially those made by vapor-phase cracking, have a marked tendency to lose their antiknock value during storage. This effect seems to result from the formation of certain knock-inducing substances, presumably peroxides, due to exposure to air, and can be prevented by the addition of certain antioxidizing agents. This loss in antiknock value on storage is believed to account for many of the disputes that have arisen as to the antiknock value of this type of product, and for such products it probably will be necessary to devise an additional test that will involve heating in contact with oxygen or air for some period of time and then redetermining the antiknock value to see whether it is stable. As yet no standard test has been worked out for this purpose.

Tests for Gum Formation

Some gasolines, particularly those cracked under vapor-phase conditions, if allowed to stand in contact with air for any considerable time, tend to deposit small quantities of resinous materials in the bottom of the container and will form similar gummy deposits in the gasoline tank and lines and particularly around the inlet valve and in the engine, where the fuel is finally evaporated. While very few commercial gasolines ever give trouble on this account, the desire to secure better antiknock values by vapor-phase cracking makes this problem one of increasing importance, especially since cus-

[5] Paper on The Influence of Atmospheric Conditions on Knock-Testing, by Donald B. Brooks, not yet published.

tomary refining methods for reducing gum generally result in reducing antiknock value as well.

For many years the only recognized test for gum was the so-called copper-dish test, which involves evaporating 100 cc. of gasoline in a copper dish on a steam bath, drying it to constant weight, and weighing the milligrams of residue. It is very generally recognized (23 and 24), however, that this method of testing is extremely difficult to check and that its results are frequently not at all comparable with those under service conditions.

Gum Problem Clarified

Voorhees and Eisinger did a great deal to clarify this situation by their paper (25) presented before the American Petroleum Institute in 1928, which showed that two separate problems really are involved in the determination of gum: first, the quantity of gum *actually present* in a gasoline at a given time, which can be determined by evaporating the gasoline in the absence of air, as first suggested by Cooke (26); and, second, *potential gum* or *gum-forming constituents* whose presence in gasoline causes it to form actual gum on storage in contact with air. The work of these authors also showed that only *actual*, or pre-existent, gum deposited in an engine under service conditions, the time of evaporation apparently being too short to produce additional gum from the gum-forming constituents under these conditions. Therefore the Cooke test or similar methods of evaporation in the absence of air gives the best indication of the suitability of a gasoline that is to be used very shortly after testing.

On the other hand, if a gasoline is to be stored for some time before using, even if this storage be in the customer's own tank, attention must be paid to the gum-forming constituents present in the gasoline. The copper-dish test does give some rough indication of these gum-forming constituents because of the exposure to air during the evaporation, but it fails to distinguish between actual gum and potential gum and gives variable results due to the virtual impossibility of standardizing the rate of evaporation or the circulation of air over the surface.

Two methods were proposed by Voorhees and Eisinger for the determination of gum-forming constituents: one, an oxygen-absorption test in which the gasoline was held at 210 deg. fahr. in the presence of oxygen under moderate pressure, the rate of oxygen consumption being measured; the other involved heating the sample with oxygen under pressure under specified conditions for a definite period and noting the quantity of actual gum present at the end of the time. The first test is specially instructive in that it shows that the rate of oxidation of all gasolines is very slow at the start, but eventually every gasoline, even though ordinarily regarded as stable, shows a rather sharp increase in the rate of gum formation. In the case of vapor-phase cracked gasoline, this "period of induction" is frequently less than 100 min., while liquid-phase-cracked gasoline generally runs over 1000 min., and straight-run gasoline over 2000 min. before the increase in oxygen consumption is observed. The general shape of this curve indicates that the oxidation of gasoline, which results in the formation of gum, is an autocatalytic reaction; that is, the first products of oxidation, which probably are peroxides, tend to speed up the rate of oxidation of the remainder of the gasoline. The existence of this induction period probably accounts for the great variability of results from the copper-dish test, as relatively small variations in the time of exposure might easily make large differences in the amount of gum formed.

The time required to give similar amounts of gum formation in actual storage at ordinary temperatures undoubtedly is several hundred or a thousand times as great as that in the presence of pure oxygen at these elevated temperatures, but this test should give a reasonably good degree of coordination with the behavior of the gasoline in storage.

Voorhees and Eisinger's general conclusions are substantially confirmed by several recent investigators (27 to 29). Wagner and Hyman (29) point that Voorhees' actual gum in solution is in a somewhat different chemical or physical state from the gum that is left on evaporation and therefore prefer to call the former "pseudo gum," although this does not in any way affect the validity of the test.

Egloff and others (30) report that gum formation in storage and also loss of antiknock value can be prevented by adding to the gasoline certain inhibiting agents, and this is confirmed by Voorhees (31). This may very likely lead to the elimination of the gum problem in the future.

No gum test has as yet been standardized by the A.S.T.M., but its committee on gasoline is actively working on this subject, and it is probable that two standard tests along the lines of those herein mentioned will be worked out in the near future. As to the proper limits for these tests, too little information exists to permit the drawing of definite conclusions, although Voorhees and Eisinger indicate that the limit for actual gum should be about 10 mg. per 100 cc. and that, for a gasoline to be safe for a year's storage, their oxygen gum-test should not show more than 10 mg. per 25 cc. However, Herthel and Apgar's results (28) indicate that some other factors may be involved in gum formation in storage, especially in the presence of light.

Inadequacy of the Gravity Test

One of the few rewards for the work involved in preparing a paper such as this is the opportunity to pay one's respects (?) to "gravity," which was once the only test or specification for gasolines and still remains embodied in some State laws, although all technologists agree as to its lack of significance from a practical standpoint.

The facts regarding the significance of gravity are very simple and indisputable; of two gasolines from the same crude, the one that is lighter, and hence higher in Baumé or A. P. I. gravity, will have a greater *average* volatility, although whether this will be reflected in easier starting, more vapor lock or less crankcase-oil dilution depends entirely on the distillation range, of which the gravity gives no indication. On the other hand, as between gasolines of similar distillation range made from different crudes or by different kinds of cracking operations, it is almost always true that, the heavier the gasoline is, the higher are its antiknock rating and fuel value per gallon, so that with Government specifications and commercial practice rather closely limiting the boiling range of most motor gasoline, it is generally true that the customer who selects a high-gravity gasoline gets a poorer product from the standpoint of knocking and of fuel economy than the man who picks the heavier

gasoline. This affords an excellent illustration of the undesirable results of adopting a test simply because it is easy to make, without regard to its actual bearing on performance.

Copper-Strip Corrosion Test

Certain gasolines contain substances that are likely to cause corrosion or scaling of steel or other metals. The use of such gasolines for any considerable period is likely to cause troublesome clogging of fuel lines or screens, undue enlargement of the carbureter jet and, in some cases, eating out of some important part of the fuel system. Dissolved sulphur and hydrogen sulphide are the two worst offenders in this respect, but both of these substances and anything else likely to cause corrosion in service can be readily detected by the standard A.S.T.M. Corrosion Test for Gasoline No. D 130-27T, which involves heating a polished copper strip in contact with gasoline for 3 hr. at 122 deg. fahr, and noting any marked discoloration. The copper-dish test gives a much less reliable indication of the same general nature. It should be understood that the corrosion test is entirely independent of the test for total sulphur content discussed later.

Deficiency of the Doctor Test

The doctor test is an old stand-by which owes its popularity more to its simplicity and appeal to the eye than to any great merit. For this reason the A.S.T.M. has never standardized the test, which consists in shaking the gasoline with an alkaline solution of lead oxide, usually with the addition of some sulphur. It affords a simple means of detecting the presence of mercaptans or dissolved hydrogen sulphide in a gasoline. However, it fails to detect one of the most common corrosive substances, dissolved sulphur, although it is a striking test for mercaptans, which are, in general, not corrosive. The removal of mercaptans and hydrogen sulphide is a simple process that is employed by almost all large refiners, largely to improve the odor of the gasoline. No serious objections to the doctor test can be raised, but it must not be considered a substitute for the somewhat more difficult corrosion test.

Total Sulphur Content

The significance of the total sulphur content of a gasoline and the desirability or undesirability of the Government limit of 0.1 per cent sulphur has been the subject of controversy for several years. In refining gasolines made by cracking high-sulphur crudes, or gas-oils, it is frequently quite difficult to reduce the sulphur content below the Government specification of 0.1 per cent without incurring refining losses as high as 10 or 20 per cent, and refiners handling this kind of crude have therefore raised the question whether the practical value of the sulphur specification is sufficient to justify such large refining losses, pointing out that many European countries have no such specification and that some refiners have put out high-sulphur gasolines for considerable periods without having complaint.

On the other hand, virtually all of the real investigation work reported has shown that gasolines containing much more than 0.1 per cent sulphur are likely to cause serious corrosion under certain conditions. This corrosion due to total sulphur content does not occur in the fuel induction system, but in the engine and crankcase, and occurs only when conditions are such as to permit the condensation of water on the cylinder-walls or in the crankcase. This water dissolves a certain amount of sulphuric acid that has been formed by the combustion of the sulphur compounds in the gasoline; and, while amounts of sulphur below 0.1 per cent have never been found to cause any serious trouble, sulphur contents substantially above this amount have been shown to cause very rapid and serious corrosion (40 and 41), especially of wristpins, bearings, starter chains and even cylinder-walls. The widespread adoption of crankcase ventilation, control of cooling-water temperature and so on has greatly reduced the likelihood of water condensation and the danger of such corrosion in most of the new cars. However, the time has not yet arrived, at least in the northern half of this Country, when it can be said with any degree of confidence that it would be safe to make any substantial increase in the present limit on total sulphur content (42). The Bureau of Standards is at present investigating this subject thoroughly and may very likely find that, if the design of engines continues to improve, the revision of this specification may become desirable.

The generally accepted test for the total sulphur content of motor fuels is the A.S.T.M. Lamp Method for Sulphur No. D 90-29T. While its accuracy still leaves something to be desired (43 and 44), it is rapid and convenient, and is satisfactory for most practical purposes (45).

Color and Color Stability

Color is another property that is so easily measured[6] and so apparent to the eye that it has been given a prominence greatly in excess of its actual significance, as has been recognized by the United States Government in eliminating the color test from its specifications. In general, vapor-phase-cracked gasolines tend to be much yellower and to have more gum than ordinarly gasolines. This fact has led many to believe that color is an indication of gum or gum-forming constituents. It has been repeatedly shown, however, that yellow gasolines may contain practically no gum and water-white gasolines may contain large quantities of gum, so this method of test cannot be relied upon as a definite indication of gum. While it thus seems to have no possible bearing on performance, many marketers still insist on color specifications.

Most cracked gasolines tend to become slightly yellowish during storage, and this is undesirable for marketing reasons. It has been found that holding a 4-oz. bottle of gasoline and air or, preferably, oxygen, in an oven at moderately elevated temperatures will give an accelerated indication of whether the gasoline will probably hold its color. Acceleration by sunlight or ultraviolet light gives different results that seem to bear little relation to change of color in ordinary dark storage.

Miscellaneous Properties

In view of the modern predominance of closed cars, a good *odor* is still a matter of some importance to the comfort of the passengers. Even as ambitious a body as the A.S.T.M. has not attempted to standardize a test for this property, although gasolines that pass the doctor test and are free from gum-forming constituents generally have a satisfactory odor, as the two foregoing

[6] Generally measured by the Saybolt chromometer A.S.T.M. Method D155-23T.

tests tend to indicate the presence of the malodorous compounds most likely to be present. These are mercaptans, on the one hand, and peroxides or aldehydes, on the other hand.

It is important that a gasoline be free from *water*, traces of *acidic compounds* or any *non-volatile residue*. However, the corrosion test will, in general, detect the presence of any acidic compounds, and the gum tests reveal any non-volatile residue. While water in small quantities frequently collects in an automobile gasoline tank or gasoline filter, it is more likely to come from the condensation of moisture in the gasoline tank than from water having been present in the gasoline as delivered. When a car is driven from a warm garage into the cold outside air, a small amount of moisture is almost certain to be condensed out of the air in the gasoline tank, and this sinks to the bottom of the tank, where it has little chance to re-evaporate and so gradually accumulates over a period of months and may cause occasional trouble, especially by freezing in the fuel lines in winter.

The viscosity of a gasoline is of little direct importance, except that marked variations in viscosity, or gravity, may affect the mixture ratio delivered by a given carbureter-setting and thus indirectly affect power and economy.

Importance of Cooperation Between Engineers

As might be expected, almost every desirable property of gasoline, such as high volatility, high antiknock value, low sulphur content and low gum content, cost money to obtain and are bound to be ultimately reflected in the cost of gasoline to the consumer. In many cases the intelligent cooperation of the automotive engineer with the petroleum engineer will markedly decrease the need for such stringent specifications or prevent the trouble that may result if the specification limits are exceeded, and such cooperation is certainly to the advantage of both industries and of the public. Specific examples of important ways in which the automotive engineer can and should improve present conditions are:

(1) More care in design to prevent overheating the fuel lines, vacuum tank, carbureter and other parts of the fuel system. This will decrease evaporation losses and the tendency to vapor lock and make it possible to supply more-volatile gasoline of better starting characteristics. Also, the use of wide passages and the avoidance of sharp bends or high suction-lifts in the gasoline lines will tend to decrease vapor lock.

(2) The general use of crankcase ventilating devices or other means of preventing condensation of water in the cylinders and crankcases of engines. This will greatly reduce the need for a low sulphur content in the gasoline and increase the amount of crude available for making satisfactory gasoline. It will also prevent excessive amounts of crankcase-oil dilution.

(3) More uniform cooling of automobile engines and the elimination of localized hot-spots. The presence of localized hot-spots has been shown to greatly increase the tendency of a given fuel to detonate, especially in the case of natural hydrocarbon antiknocks. Keeping down the temperature of exhaust valves, spark-plugs and piston heads should minimize detonation and make possible the use of higher compression-ratios. This is an argument for liquid-cooled rather than air-cooled aircraft engines. For the same reason, excessive heating of the intake air should be avoided, especially when running with wide-open throttle.

For its part, the petroleum industry can, and I am sure will in the future, furnish the automobile industry with gasoline of higher antiknock value and better antiknock stability without getting into any difficulties from gum content. It will be noted that all these improvements are related to the three testing methods that are not yet satisfactorily standardized.

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THE DISCUSSION

QUESTION:—What is the greatest percentage of sulphur found in gasoline?

R. E. WILSON:—Not much high-sulphur gasoline will be found in Milwaukee and the vicinity; the benzol blends hereabouts probably contain the highest percentage. I have seen such blends show as high as 0.4 per cent of sulphur. Not all benzol blends are like that, but the cheaper benzols go into gasoline.

QUESTION:—What happens when a gasoline containing gum is used?

MR. WILSON:—At present the percentage of gasolines containing gum is small. Most gasolines are perfectly safe from this standpoint, but an increasing number of the vapor-phase-cracked gasolines which are coming in are likely to form gum if they are stored for a considerable time. The most likely effect in nor-

mal operation is the formation of a deposit around the inlet valves, and the next most likely effect is clogging of some part of the fuel system, but that usually results only from a considerable accumulation; the fuel lines are more likely to become plugged with dirt, scale or water.

Many of you probably have experienced the freezing of a fuel line in very cold weather and blamed the oil company. An analysis of conditions indicates, however, that in most cases, it is due to condensation of water vapor in the fuel tank. When the car is taken out of a warm garage into cold air, most of the moisture in the warm air in the tank condenses in a very thin film on the walls of the tank and sinks to the bottom where it is prevented from evaporating by the gasoline above. After a few months, two or three spoonfuls of water may collect, and, if a few drops of that gets into the fuel line when the temperature is below freezing, the ice stops the gasoline flow.

RALPH B. HUBER[7]:—What kind of chemical is used when agitating the tank to remove sulphur?

MR. WILSON:—The different types of sulphur are removed by different agents; the two principal refining chemicals ordinarily employed for our particular problems are sulphuric acid, which removes unsaturated compounds, and quite a number of sulphur compounds, and Doctor solution, which is sodium plumbite and which reacts with mercaptans and hydrogen sulphide and removes them. The Doctor solution removes the most objectionable compounds, but the acid removes a larger percentage of the total sulphur. The acid is, of course, neutralized and washed out.

Differences in Types of Gasolines

JOHN BRHEL[8]:—Is there any difference in fuel value between first runs of gasoline and cracked gasolines, if they are of the same gravity?

MR. WILSON:—There are a number of minor differences. Suppose that the three different types of gasoline—straight-run, liquid-phase-cracked and vapor-phase-cracked—are made to have the same distillation range or volatility. The straight-run will as a rule have the highest Baumé gravity and poorest antiknock value; it will be the most stable and will have slightly less fuel value per gallon. The liquid-phase will have somewhat better antiknock quality, be less stable, although adequate for a year's storage under ordinary conditions, and have slightly more fuel value per gallon but not quite so much per pound. The vapor-phase-cracked product will in general be distinctly better in antiknock properties, lower in gravity, yellow in color and much more likely to form gum and lose antiknock value in storage. It will probably give slightly higher mileage per gallon.

How Copper Containers Affect Fuel

F. M. YOUNG[9]:—Does the copper in copper tanks in fire trucks have some chemical action that destroys the antiknock value or some other qualities of the gasoline so that the truck might perform poorly when running to a fire?

MR. WILSON:—Copper seems to accelerate the oxidation and formation of gum in gasoline. Even gasoline that is fairly stable for storage in steel gasoline tanks under ordinary conditions, if stored in a copper tank of some fire apparatus, especially in a warm room for two or three months, is likely to deposit gum and give trouble. Two such cases have been reported in the East.

MR. YOUNG:—What would you recommend in place of copper?

MR. WILSON:—The best thing to do is use steel tanks.

MR. YOUNG:—But water in gasoline always rusts the steel.

MR. WILSON:—I never heard of a steel gasoline tank rusting out, though I do not say that it never has occurred. Copper is a metal we always avoid around refineries. It is very much inferior to steel in resistance against sulphur compounds in general, and even steel is not any too good.

WILLIAM F. KRENZKE[10]:—We have been storing some equipment in a room through the winter until we were ready to use it, and find that a sort of plastic coating has formed over the copper screen inside of the gas tank. Otherwise the tank is in perfect condition, showing no signs of corrosion, but the copper piping is covered with a green coating and the screen and lower portion of the intake tube are covered with varnish-like substance.

MR. WILSON:—That is gum. The copper screen accelerates the formation.

MR. KRENZKE:—We find this condition only in the Gulf regions from Florida west, and also in the State of Washington: it seems to be local.

MR. WILSON:—I should say it is due to the type of gasoline you are buying in those localities. Normally that would not be expected to happen with most gasolines. Of course, the higher the temperature is in storage, the more likely you are to have gum formation. Even good gasoline, stored for a long time at elevated temperatures and with good contact with air will eventually form gum, particularly if copper is present.

MR. KRENZKE:—Is a brass screen less susceptible to this reaction that forms gum?

MR. WILSON:—I am not positive about brass, but I think that any lacquered screen or a steel screen or chromium-plated screen would work perfectly well. If you would lacquer the screen, that probably would keep the metal out of contact with the gasoline.

How Good Results Are Spoiled

J. B. FISHER[11]:—I have enjoyed Mr. Wilson's talk on gasoline and the problems the oil companies have encountered in producing a gasoline for the industry. We have had quite a bit of fun at Waukesha in the development of the little variable-compression engine to which he referred and especially with the methods of measuring the knock.

We have tried several methods out there, such as dropping a steel ball a given distance and producing a sound that corresponded with the knock we hear in the engine, and also measuring the amount of work actually done by the knock in the evaporation of a certain quantity of water. We have finally been able to arrive at some rather accurate methods of comparing the knock values of the different fuels, so that independent observers can take readings on the same fuels and get consistent results that are remarkably close,

[7] Chemist, Fisk Rubber Co., Chicopee Falls, Mass.

[8] Production service engineer, Kearney & Trecker Corp., West Allis, Wis.

[9] M.S.A.E.—President, general manager, Young Radiator Co., Racine, Wis.

[10] M.S.A.E.—Chief engineer, Jacobsen Mfg. Co., Racine, Wis.

[11] M.S.A.E.—Chief engineer, Waukesha Motor Co., Waukesha, Wis.

which is considerably different from listening to the knock and attempting to arrive at any consistent knock-value.

Vaporization in the manifold is certainly the problem that confronts us all. As Dr. Wilson has shown, the distillation test is a very crude approximation of what is actually going on in the manifold. The time element is another very important point that Dr. Wilson did not emphasize; for instance, you can make the manifold operate perfectly in some certain class of service, take it off and put in some particular installation, where the load factor varies ten times as fast, fluctuating on and off rapidly all day long, and the carburetion and manifolding system that is giving 100 per cent satisfaction in truck or bus may fail to handle this other class of service. The time available to vaporize the fuel after it leaves the carbureter is an extremely small fraction of a second, and when the automotive engineer does get a system to work satisfactorily, he should leave it alone, making no changes until he is sure the changes will enable it to handle all conditions better.

An example that illustrates the importance of this is that of a car that had an enviable record of good vaporization of fuel and had given excellent mileage. This year the engineers put the exhaust manifold in a different relation to the inlet manifold and now they are wondering why they are having complaints from some of their customers that they do not get the good acceleration and mileage of the last few years. I think it is a case of the engineers working a little too much on a problem after the problem had been solved.

MR. HUBER:—In the chemical purification of gasoline, are any of the products that are formed and collected at that point of any commercial value and, if so, what are the products?

MR. WILSON:—A rather small amount of lead sulphide, which is a waste product, is formed and sold to lead smelters. The sludges that are formed from sulphuric-acid treating are generally saved and sometimes burned as fuel; however, there are no by-products that are particularly worth working for, it is simply a question of utilizing everything.

[12] M.S.A.E.—Research engineer, Waukesha Motor Co., Waukesha, Wis.

[13] Jun. S.A.E.—Assistant superintendent, Wadhams Oil Corp., Milwaukee.

A. W. POPE. JR.[12]:—Will you tell us something about your new lubricating oils, which seem to have some characteristics that are unusual?

Properties of New Lubricating Oil

MR. WILSON:—The principal contribution these oils have made to automobile lubrication is to really combine advantages of paraffin-base and coastal-base types of crudes. The characteristic lubricants from paraffin-base oils have a good temperature coefficient, that is, they do not thin out rapidly at high temperatures or thicken badly at low temperatures, which means that they are better adapted for variable-service conditions. On the other hand, they tend to have a higher pour-test and also show a rather high Conradson test for carbon. Coastal oils have a low Conradson carbon-test and low pour-test, but get very thick at low temperatures and thin out badly at high temperatures. We found it possible to get a remarkably good combination of low temperature-coefficient, low pour-test and very low carbon-residue. Those are the three most important properties of a motor oil. They are obtained by a special method of refining, rather too complicated to describe here.

EARL L. KULLMANN[13]:—Does the vapor pressure of gasoline mean anything in regard to volatility on the distillation curve?

MR. WILSON:—Yes, the vapor pressure is measured by the 10-per cent point on the A.S.T.M. distillation test, as has been shown by the Bureau of Standards. You can get the 10-per cent point corrected for loss and will then have not only a corresponding point but the actual temperature at which boiling will begin, within 1 or 2 deg. There is one exception which occurs if there is any considerable amount of propane from a wild casinghead blend, but refiners now generally recognize that more than traces of propane do not belong in gasoline.

MR. KULLMANN:—I was thinking mainly of a physical test, such as the bomb test.

MR. WILSON:—The bomb test was developed before this relationship with the 10-per cent point was understood and it is still part of shipping regulations for casinghead gasoline and products of that kind.

The Trend of Motorcoach Design

(*Concluded from p.* 23)

emergency, the driver can get the absolute maximum performance out of his vehicle to avoid an accident. That oftentimes means stepping on the accelerator so that the driver can either get ahead or get away from whatever the dangerous circumstance might be.

MR. HORNER:—It seems to me that the policy pursued by most of us when we have a problem to solve is an old one and therefore should be followed by those operating motorcoaches or railroads or anything else. If there is a company that has had good success in the operation of motorcoaches from the standpoint of few or no accidents, I would invariably recommend that any company which was having much trouble in that direction or which was starting a motorcoach operation, analyze the operation where the company was so successful. There is a large motorcoach operation by a well-known railroad in this Country that handles a great many passengers per day and per year, and its accident record is almost entirely clean. Undoubtedly the motorcoach operators in various parts of the Country could learn much, not only from that particular company, but also from many others, where they have reduced accidents to the minimum.

Regarding driver control, I know of a motorcoach operation that was started within the last year. After deciding on where they were going to operate motorcoaches, the most important problem, as they considered it, was the matter of securing competent drivers. They compiled an examination sheet, called for applicants and made various tests, physical examinations and so on. Only 40 per cent of those applying passed the examination, physical and otherwise, and 99 per cent of those who applied were at the time, or had been, drivers of motorcoaches.

Bearing Bronzes with Additions of Zinc, Phosphorus, Nickel and Antimony[1]

By E. M. Staples[2], Dr. R. L. Dowdell[3] and C. E. Eggenschwiler[4]

Semi-Annual Meeting Paper — *Illustrated with* Photographs and Charts

Seven basic copper-tin-lead bearing-bronzes having high copper contents were studied by the application of various mechanical tests, such as Brinell hardness, resistance to impact, resistance to repeated pounding and resistance to wear. The effects of various additions were investigated by preparing test bearings of the same base alloys with additions of zinc, phosphorus, nickel and antimony, taken singly, and applying the same tests to these.

The preparation of the test castings and the methods of testing are described in detail. The chemical analyses are given for the 40 different alloys tested; and the results of the various tests on each group of alloys are reported and discussed in detail, with the observations charted and tabulated for convenient reference.

A tabulation of the specifications of 54 different bearing bronzes now in use is included in the paper.

Dr. Dowdell presented and discussed the paper for the authors. The discussion emphasized the necessity of complete film lubrication and mentioned porous synthetic bearing alloys as a means of securing this. Contributed discussion called attention to improvements and economies that could be made in specifying and purchasing bearing bronzes by consultation with bearing manufacturers.

At the present time, there are many specifications for bearing bronzes of the copper-tin-lead type which differ mainly in the amounts of other elements contained. The need for most of these specifications may be questioned, when it is considered that the tin and lead contents of these alloys are usually within the range of 0 to 15 per cent and 0 to 30 per cent respectively. As a large number of bronze alloys having different compositions are used under similar conditions of service, it appears that there is little agreement as to the proper bronze compositions for given service conditions. For example, automotive engineers have diversified opinions as to the most suitable material for piston-pin bushings. Some specify an alloy with a lead content not to exceed 1 per cent; others indicate that their choice is a material having 10 per cent of lead, while still others are of the opinion thatpiston-pin bearings should contain from 15 to 20 per cent of lead.

Lead and zinc are classed as impurities in some specifications, while in others of a similar nature they are listed as essential constituents. Some of the present specifications for bronze bearing metals are given in Table 1.

In a previous Bureau publication, prepared by H. J. French, S. J. Rosenberg, W. LeC. Harbaugh and H. C. Cross[5], the mechanical properties and the testing technique used in determining wear were reported upon for the copper-tin-lead alloys used in railroad equipment. The alloys contained small quantities of common impurities. In a later Bureau publication on bronze bearings, by H. J. French and E. M. Staples[6], the alloys were made from commercially pure materials. It is uneconomical for bearing metals to be made wholly from new or virgin metals. The high value of copper, tin and lead makes the reclamation of unserviceable bearings desirable. These "secondary metals" vary not only in the proportions of copper, tin and lead but also in percentages of various other elements such as zinc, phosphorus, antimony, nickel and iron.

The subject of impurities is of considerable economic importance in the production of bearing bronzes, the cost of bearings to the consumer being governed largely by the limitations as to the kind and percentage of impurities. It is advantageous, therefore, to both the consumer and the manufacturer to know the effects of different impurities on the properties. This investigation on the effect of various additions on the properties of bronzes forms one phase of the general study of bearing bronzes which has been in progress for over two years in cooperation with the Bunting Brass & Bronze Co. on the research associate plan[7].

Alloys Studied and Procedure

The program consisted of a study of the effects of various additions—namely: Zinc, phosphorus, nickel and antimony—on the properties of copper-tin-lead alloys, most of the alloys studied being selected from among those in common manufacture. In order to widen the scope of the investigation, some alloys not usually considered as bearing metals were included.

Five groups of alloys were prepared. In the first group, the additions were kept as low as was practicable. In the four additional groups, approximately the same ratios of copper-tin-lead were maintained as in the first group, but each group contained an additional metal. These additions consisted of zinc, 4 per cent; phosphorus, 0.05 per cent; nickel, 2 per cent and anti-

[1] Publication approved by the Director of the Bureau of Standards, City of Washington. The authors acknowledge their indebtedness to H. K. Herschman, associate metallurgist, and S. J. Rosenberg, assistant metallurgist, for aid in preparation of this report and to the skillful assistance of L. D. Jones, senior laboratory mechanic, for his material help in the founding of the bronzes.

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[3] Senior metallurgist, Bureau of Standards, City of Washington.

[4] Research assistant for the Bunting Brass & Bronze Co., Bureau of Standards, City of Washington.

[5] See *Bureau of Standards Journal of Research*, September, 1928, p. 343; and *Proceedings of the American Society for Testing Materials*, 1928, part 2, p. 298.

[6] See *Bureau of Standards Journal of Research*, June, 1929, p. 1017; and *Proceedings of the American Society for Testing Materials*, 1929, part 2, p. 450.

[7] See Bureau of Standards Circular No. 296, 1926.

mony, 1 per cent. The compositions of the various test bronzes are given in Table 2.

Preparation of the Test Castings.—In order that the structure and properties of the test castings should approximate those of the average bushings used in the automotive and allied industries, the test castings were of relatively thin section. The dimensions of these test castings together with the methods of gating are illustrated in Fig. 1.

In the preparation of these castings, 1500 lb. of a base alloy of copper and tin of approximately 90 per cent copper and 10 per cent tin were first melted in an open flame gas-fired furnace and poured into small notched-bar ingots. These ingots were used as the base alloy for subsequent melts, the pure metals necessary to prepare alloys of desired compositions being added These smaller melts, weighing about 40 lb. each, were made in a gas-fired crucible furnace. Additions of zinc, lead, tin, antimony or phosphorus were made to the molten base alloy after the crucible had been removed from the furnace and carefully skimmed, while additions of copper and nickel were made at the time of charging the crucible. In all cases, the metal was melted under a slag approximately 50 per cent of borax and 50 per cent of limestone.

All of the heats were poured at temperatures as close as practicable to 2000 deg. fahr. (1095 deg. cent.). Deviations from this pouring temperature were slight, with the exception of the alloys No. 10 and No. 133, as listed in Table 2. The high copper-content of alloy No. 10 necessitated a higher pouring temperature, about 2100 deg. fahr. (1150 deg. cent.), and it was found desirable to pour alloy No. 133 at a slightly lower temperature, about 1950 deg. fahr., on account of its high lead-content. Observations made during the process of casting showed that both antimony and nickel have a strong effect in preventing segregation of lead. It was also noted that melts containing antimony and nickel showed a considerable tendency to oxidize, both in the crucible and in the mold.

The casting conditions were kept as nearly constant as possible, because it was shown by H. C. H. Carpenter, Miss C. F. Elam[8], C. P. Karr[9], and F. W. Rowe[10] that

[8] See *The Journal of the Institute of Metals*, vol. 19, 1918, p. 155.

[9] See Bureau of Standards Technologic Paper No. 59, 1916.

[10] See *The Journal of the Institute of Metals*, vol. 31, 1924, p. 217.

TABLE 1—MISCELLANEOUS BEARING BRONZE SPECIFICATIONS IN PRESENT USE

	Composition, Per Cent														
	Copper		Tin		Lead		Zinc		Phosphorus		Nickel				Other Ele-ments,
Alloy	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Antimony, Max.	Iron, Max.	Max.
					Bronzes Having Less Than 4 Per Cent of Lead										
A1	87.0	90.0	9.0	10.0		0.7	0.2	0.5	0.6	0.9					2.5
A2	87.7	89.7	9.0	11.0	0.5	1.5			0.2	0.4					2.6
A3	85.7	87.7	9.0	11.0	2.5	3.5			0.2	0.4					2.6
A4	86.0	89.0	9.0	11.0		0.2	1.0	3.0						0.06	4.0
A5	84.0	85.5	14.5	15.5		0.5			0.09	0.12					1.4
A6	85.0	89.0	7.5	8.5	0.75	1.5	2.25	4.25	0.05	1.0					4.45
A7	86.0	88.5	9.0	11.0	1.25	1.6	1.5	2.5							2.25
A8	87.0	89.0	9.0	11.0	2.0	3.0		0.75							1.25
A9	86.0	88.0	9.5	10.5	0.6	1.0	1.5	2.5							2.4
A10	83.5	85.5	12.5	14.5			1.5	2.5							2.5
A11	81.0	83.0	9.0	11.0	1.5	3.0		1.0			5.0	7.0			4.5
A12	86.7	87.7	8.45	9.95			2.6	3.6							2.25
A13	83.0	85.0	11.25	12.75		0.5	3.0	4.0							2.75
A14	81.0	83.0	9.0	10.5	2.0	3.0					5.0	6.5			3.0
A15	86.5	88.5	10.15	11.65			1.1	2.1							2.25
A16	89.9	91.9	8.05	9.55					0.3						2.05
A17	83.0	85.0	9.25	10.75	2.0	3.0	3.0	4.0							2.75
A18	86.0	91.0	6.0	7.0	1.0	2.0	1.5	5.0		0.05		0.75	0.25	0.15	0.2
A19	78.0	82.0	4.0	6.0	2.0	3.0	10.0	16.0		0.05		0.75	0.25	0.35	0.2
A20	86.0	89.0	7.5	11.0		0.3	1.5	4.5		0.05		0.75	0.25	0.25	0.4
A21	82.0	85.0	13.0	15.0		0.2		1.5		0.05		0.75	0.50	0.1	0.3
A22	86.0	89.0	9.0	11.0	1.0	2.5				0.25					0.5
A23	88.0	90.0	10.0	12.0					0.1	0.3					0.5
A24	87.0	89.0	6.5	7.5	1.25	2.75	2.25	3.75					0.2	0.3	0.1
A25	87.0	89.0	9.5	10.5	1.0	3.0									0.35
					Bronzes Having Lead Contents Between 4 and 12 Per Cent										
B1	81.0	83.5	6.5	7.5	6.5	7.5	2.5	4.0		0.1					3.5
B2	78.5	81.5	9.0	11.0	9.0	11.0		1.0							3.5
B3	81.0	87.0	3.0	6.0	4.0	7.5	4.0	6.0							3.0
B4	84.0	86.0	4.5	5.5	8.0	10.0		1.5					0.2	0.2	0.35
B5	83.0	86.0	4.5	6.0	8.0	10.0		2.0							0.25
B6	78.5	80.5	11.0	13.0	6.5	8.5		1.0							5.0
B7	78.5	82.5	9.0	10.5	9.0	10.5		0.5	0.6	0.9					2.9
B8	78.5	81.5	6.5	8.5	10.0	12.0	1.0	2.5							5.0
B9	77.0	82.0	9.0	11.0	8.0	11.0			0.7	1.0					1.0
B10	84.0	86.0	4.0	6.0	4.0	6.0	4.0	6.0		0.05		0.75	0.25	0.25	0.2
B11	80.0	83.0	2.0	3.0	5.0	7.0	8.0	12.0							1.0
B12	82.0	85.0	7.0	9.0	7.0	9.0		0.25	0.3	0.6		1.0	0.15	0.15	0.4
B13	83.0	86.0	4.5	5.5	4.5	5.5	4.5	5.5					0.25	0.35	3.5
B14	78.5	81.5	9.0	11.0	9.0	11.0		0.75	0.05	0.25					0.25
					Bronzes Having Lead Contents Between 12 and 30 Per Cent										
C1	73.0	79.0	6.5	8.0	15.5	18.5		1.0							5.0
C2	75.0	79.0	7.0	9.0	13.0	17.0		1.0							5.0
C3	68.0	72.0	7.0	9.0	16.0	19.0		1.0			2.50	4.50			6.5
C4	73.0	77.0	10.5	11.5	12.0	14.0	0.5	1.5							0.5
C5	72.0	76.0	4.0	5.0	18.0	22.0	0.5	1.0							6.5
C6	66.0	77.0	6.0	8.0	23.0	27.0		1.0							4.0
C7	71.0	74.5	3.25	4.25	22.0	25.0									3.75
C8	69.0	71.0	1.0	2.0	28.0	30.0									2.0
C9	73.0	80.0	5.0	7.0	15.0	20.0		0.5		0.05		1.0	0.25	0.25	0.6
C10	75.5	78.5	7.25	8.75	13.5	16.5		0.5		0.25			0.5	0.25	0.75
C11	73.0		9.5	10.50	12.5	15.5	0.5	2.5				0.25	0.2	0.2	0.2
C12	69.0	71.0	4.5	5.50	23.5	26.5						0.25	0.2	0.2	0.1
C13	69.0	71.0	8.5	9.50	18.5	22.5						0.25	0.2	0.2	0.1
C14	63.0	72.0	3.0	6.0	23.0	28.0					2.0	3.0			2.0

TABLE 2—CHEMICAL COMPOSITIONS OF BRONZES STUDIED

Alloy No.[11]	Test for Which Used	Chemical Composition: Copper, Per Cent	Tin, Per Cent	Lead, Per Cent	Addition: Element	Addition: Per Cent
10	Wear	96.5	1.8	1.8		
	Mechanical	95.4	2.1	2.0		
10Z	Wear	91.4	2.0	1.9	Zinc	4.5
	Mechanical	92.5	2.0	1.8	Zinc	3.7
10P	Both	96.3	1.6	1.9	Phosphorus	0.05
10N	Both	95.5	0.9	1.6	Nickel	2.0
10A	Both	95.1	1.8	1.8	Antimony	1.0
20	Wear	73.7	11.8	14.4		
	Mechanical	73.1	12.8	14.1		
20Z	Wear	69.4	12.1	15.1	Zinc	3.2
	Mechanical	70.5	11.9	13.8	Zinc	3.8
20P	Both	72.9	12.5	14.2	Phosphorus	0.058
20N	Both	73.1	12.5	12.3	Nickel	2.1
20A	Both	72.7	12.0	13.4	Antimony	1.2
27	Wear	80.4	10.0	9.5		
	Mechanical	79.8	10.3	9.6		
	Wear	80.5	9.8	9.6		
27Z	Wear	76.5	9.4	9.8	Zinc	4.1
	Mechanical	76.4	10.1	9.1	Zinc	4.4
	Wear	77.4	9.0	10.1	Zinc	3.3
27P	Both	80.7	9.7	9.9	Phosphorus	0.045
27N	Both	79.2	9.7	9.1	Nickel	1.9
27A	Both	80.5	9.6	8.6	Antimony	1.1
72	Wear	85.8	7.3	6.8		
	Mechanical	85.3	7.3	7.2		
72Z	Wear	82.2	6.8	7.0	Zinc	4.0
	Mechanical	82.5	7.2	6.7	Zinc	3.6
72P	Both	85.7	7.5	6.9	Phosphorus	0.054
72N	Both	84.1	7.1	6.7	Nickel	2.0
72A	Both	84.6	7.2	7.0	Antimony	1.2
96	Wear	88.1	10.0	2.0		
	Wear	88.5	9.5	2.0		
	Mechanical	88.4	10.3	1.5		
96Z	Wear	83.9	9.3	2.1	Zinc	4.4
	Wear	84.8	9.9	2.1	Zinc	3.1
	Wear	84.8	9.5	2.0	Zinc	3.7
96P	Both	88.4	9.6	2.1	Phosphorus	0.043
96N	Both	87.0	9.0	2.0	Nickel	1.8
96A	Both	87.0	9.6	2.3	Antimony	1.1
125	Wear	75.3	4.5	20.1		
	Mechanical	76.6	4.6	18.9		
125Z	Wear	72.8	4.3	19.1	Zinc	3.7
	Mechanical	73.0	4.3	18.5	Zinc	4.2
125P	Both	75.0	4.8	19.8	Phosphorus	0.048
125N	Both	74.9	4.4	18.7	Nickel	1.9
125A	Both	78.3	4.3	15.6	Antimony	1.2
133	Wear	68.2	2.4	28.7		
	Mechanical	75.2	1.5	23.2		
133Z	Wear	66.3	2.2	27.8	Zinc	3.7
	Mechanical	71.0	1.4	23.8	Zinc	3.8
133P	Both	72.5	1.8	25.7	Phosphorus	0.055
133N	Both	73.3	1.5	23.1	Nickel	2.0
133A	Both	71.1	1.5	25.9	Antimony	1.1
143	Wear	85.2	14.7			
	Mechanical	84.8	15.0			
143Z	Wear	81.1	14.5		Zinc	4.4
	Mechanical	82.0	13.8		Zinc	4.2
143P	Both	85.0	14.9		Phosphorus	0.051
143N	Both	83.4	14.4	0.1	Nickel	1.9
143A	Both	83.4	15.1	0.1	Antimony	1.1

[11] Alloys having numbers without letters are base alloys, and alloys containing additions of zinc, phosphorus, nickel and antimony are distinguished by the initials of these elements added to the base-alloy number.

variations in these conditions might appreciably affect the properties of bronzes.

Test Methods.—In outlining the program, special attention was given to the causes of bearing failure in service. Bearings which have failed in service are frequently termed "worn out." This term may often be a misnomer, as wear frequently plays only a minor part in rendering the bearings unserviceable. Repeated pounding stresses cause a large percentage of failures. A survey of the possible causes of bearing failure indicated that the following properties deserved study: Wear resistance, resistance to repeated pounding, resistance to single impact, and hardness.

In the work previously reported[6], wear-resistance tests were made both with and without a lubricant, but comparisons of the alloys were made wholly on the basis of the dry or unlubricated tests. "Lubricated tests" would be of value in bearing-metal testing technique if such tests were not so difficult to control or did not require such long periods.

Under conditions of complete-film lubrication, the wear rate is extremely low. Conditions giving boundary lubrication have many experimental difficulties, so it was decided to run this series of experiments in the unlubricated condition of the Amsler machine[5 and 6].

All wear resistance tests were run in duplicate. Each bronze specimen was tested against a standard steel specimen, a new specimen being used in each case. The steel used throughout this investigation was an oil-hardened carbon-steel containing 0.93 per cent of carbon. This steel was selected because its surface hardness after treatment is nearly the same as that of the case-hardened low-carbon steel commonly used for shafts in bronze bearings. The heat-treatment and properties have been described previously by F. W. Rowe[10].

In the wear-resistance tests, the total pressure between the specimens was about 37.5 lb. The unit contact pressure, as calculated by the Hertz[12] formula for line contact, varied from 24,200 to 30,600 lb. per sq. in. This variation was due to the lateral oscillation of the upper specimen, which is a characteristic of the Amsler machine. As these pressures are known to be above the

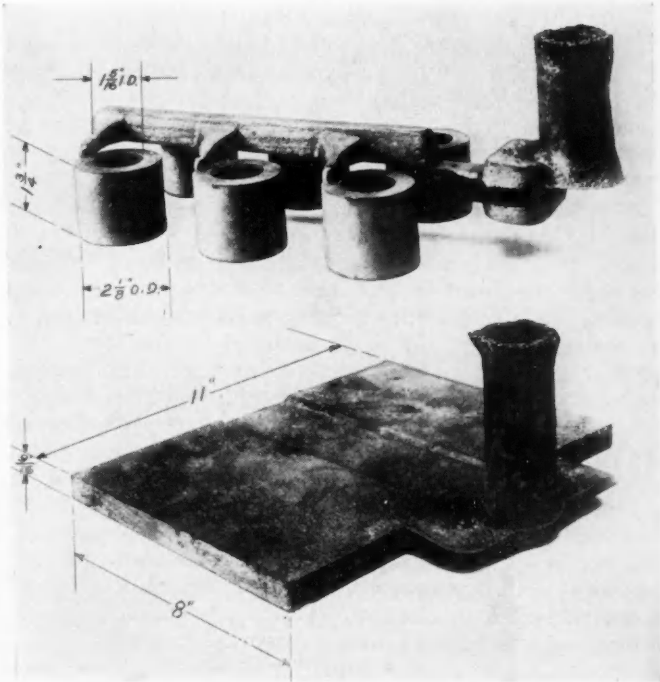


FIG. 1—BRONZE TEST CASTINGS
The Upper View Shows a Gated Casting for Wear-Test Specimens. The Lower View Is of a Casting for Impact, Pounding and Hardness-Test Specimens

[12] See Miscellaneous Papers, by Heinrich Hertz, translated by D. E. Jones and G. A. Schott, p. 163, Macmillan & Co., Ltd., 1896; also *Iron and Steel Engineer*, June, 1927, p. 305.

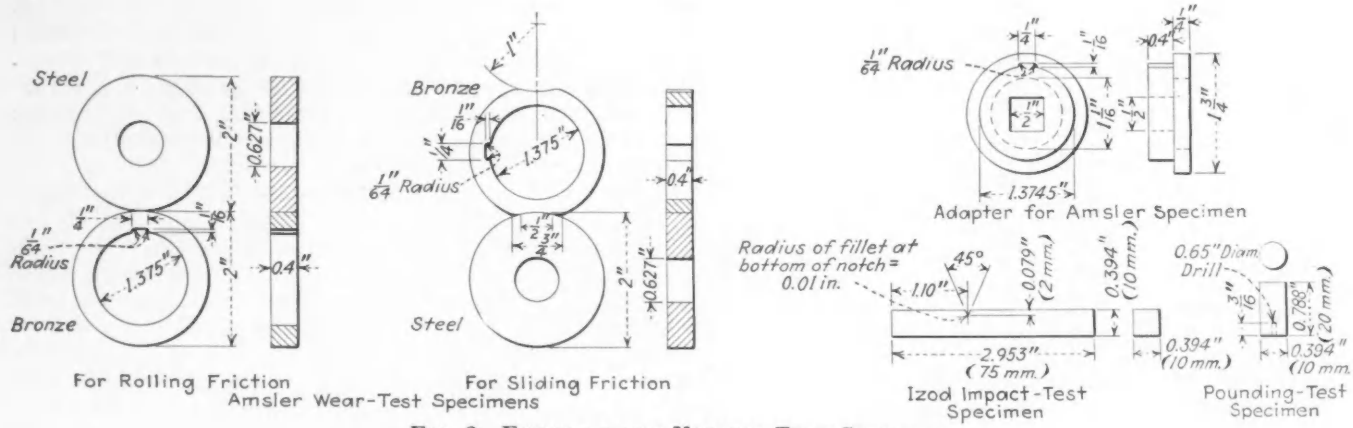


FIG. 2—FORMS OF THE VARIOUS TEST SPECIMENS

proportional limits of the various bronzes tested, it is believed that the wear rates of the alloys were accelerated by this condition.

The equipment and methods of test used for the determination of resistance to repeated pounding, resistance to single impact, and Brinell hardness have been described previously by F. W. Rowe[6]. The forms of test specimen used for the determination of wear, resistance to impact and resistance to repeated pounding are shown in Fig. 2.

Results with Basic Alloys

Wear Resistance.—The results of tests for wear resistance of the basic copper-tin-lead alloys without additions are shown by the ternary model illustrated in Fig. 3, in which the ordinates show weight losses for 10,000 revolutions, observed with the different alloys represented in the base of the model. It will be noted that an increase in the content of tin and lead, either collectively or separately, reduced the rate of wear. Other information of value was obtained from these tests, particularly the frictional force between the bronze and the steel as measured by the torque indicator. Some of the specimens tested for wear resistance showed a tendency to "flat-wheel" or become out of round during testing. Alloys having high resistance to pounding do not "flat-wheel" during the test, while alloys having low resistance to pounding show the greatest tendency toward this form of wear.

The average results indicating the relative friction between the bronzes and the steel specimens during testing are given, in the ternary model shown in Fig. 4, as meter-kilograms of work recorded by the torque indicator. Attention is called to the fact that the coefficient of friction between a bearing material and an unlubricated journal has no apparent relationship to the coefficient of friction of the same bearing and shaft if adequate lubrication is maintained. When lubrication is incomplete, as during starting or upon failure of the lubricant, the coefficient of friction of the journal and bearing is of importance. To minimize damage and seizure due to overheating, a low coefficient of friction is desirable. Attention is called to the increase in the number of meter-kilograms of work recorded by the torque indicator, as shown in Fig. 4, with bronzes having a lead content below 5 per cent.

Tests on wear resistance were made at room temperature and at 350 deg. fahr. (175 deg. cent.). The order of comparison of the alloys at 350 deg. fahr. agreed very well with that obtained at room temperature, but a consistently higher rate of wear was observed at the higher temperature.

Repeated Pounding.—The ternary model showing the resistance of the basic alloys to repeated pounding, shown in Fig. 5, is based on the number of blows required to produce a 5-per cent deformation, or upset, of the specimens. As some of the specimens did not deform 5 per cent, the resistance to pounding of the series with the additions was measured on the basis of the percentage of deformation after 100 blows.

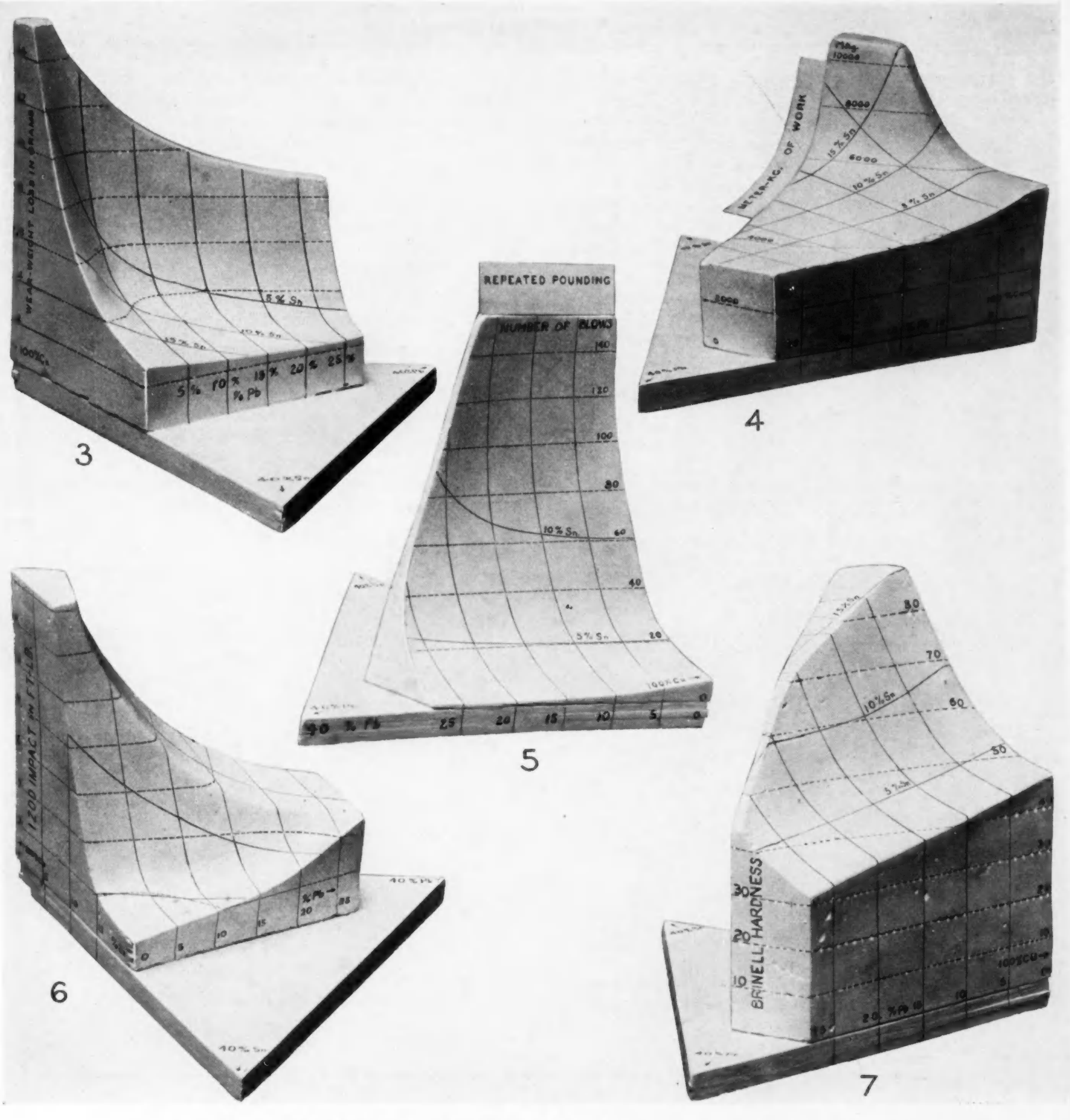
It will be noted from Fig. 5 that, so far as these tests went, the resistance to repeated pounding increased as the ratio of copper to tin decreased. This was investigated only with tin contents as high as 15 per cent. The effect of tin on increasing the resistance to pounding is probably due to two causes: first, a strengthening of the alpha solid solution of tin in copper; and, second, a further stiffening of the resulting structure by the precipitation of the delta microconstituent, according to the reaction beta → alpha plus delta.

Additions of lead might be expected to lower considerably the pounding resistance; but it should be remembered that the ratio of copper to tin is of prime importance, because it is largely the matrix of alloy that resists deformation and not the free lead contained.

Resistance to Impact.—Impact tests by the Izod method were made on all of the alloys studied. The value of this test for comparing bearing metals is largely dependent on the design of the bearing. Bearings completely supported need not be of high toughness; but the toughness of the bearing metal is of importance in a bearing that has overhanging flanges or unsupported parts which might be subjected to shock.

The notch-toughness values obtained on the basic alloys are shown in the ternary model illustrated in Fig. 6. It was found that an increase of tin up to about 8 per cent, had little effect. When the tin content was above that value, a sharp decrease in toughness resulted, due primarily to the brittleness of the alpha-delta microconstituent, as shown by W. L. Kent[13]. A progressive increase in the lead content produced a gradual decrease in toughness. Evidently this was because free lead is relatively very low in its impact toughness and also because the occurrence of

[13] See *The Journal of the Institute of Metals*, vol. 35, 1926, p. 45.



TERNARY MODELS SHOWING RESULTS OF VARIOUS TESTS ON BASE BRONZE

FIG. 3—WEAR RELATION

The Position of an Ordinate on the Triangular Base Indicates the Percentages of Copper, Tin and Lead. An Ordinate at the Left Corner Represents Pure Copper, One at the Nearest Corner Represents an Alloy of 60 Per Cent Copper and 40 Per Cent Tin and an Ordinate at the Right Corner Represents 60 Per Cent Copper and 40 Per Cent Lead. The Height of the Ordinate Represents the Wear, Measured by the Weight Lost during a Test Run of 10,000 Revolutions of the Bronze Specimen, without Lubrication

FIG. 4—RELATIVE FRICTION

An Ordinate at the Right Corner Represents Pure Copper, One at the Rear Corner Represents 60 Per Cent Copper and 40 Per Cent Tin, and One at the Front Corner Represents 60 Per Cent Copper and 40 Per Cent Lead. Ordinates Indicate the Amount of Work Done in Testing during 10,000 Revolutions, in Meter-Kilograms, and Is Proportionate to the Frictional Resistance between the Steel and Bronze Specimens at Atmospheric Temperature and without Lubrication

FIG. 5—EFFECT OF REPEATED POUNDING

Arrangement of Ordinates Is as in Fig. 4. Height of Ordinates Indicates the Number of Blows Required To Upset the Specimen 5 Per Cent at Atmospheric Temperature

FIG. 6—IZOD IMPACT RESISTANCE

Arrangement of Ordinates Is as in Fig. 3. The Vertical Scale Indicates Impact in Foot-Pounds

FIG. 7—BRINELL HARDNESS

Arrangement of Ordinates Is as in Fig. 4. The Vertical Scale Indicates the Brinell Hardness, As Tested with a 10-Mm. Ball and 500-Kg. Load at Atmospheric Temperature

the particles of lead in the bronze matrix reduced the effective cross-section of the specimen.

Brinell Hardness.—The results of Brinell-hardness tests on the basic alloys, using a 10-mm. ball and 500-kg. load, are shown in Fig. 7. The Brinell hardness reported on the basic alloys showed the expected trends, which are an increase in hardness with an increase in the tin content and a gradual decrease in hardness with a progressive increase in the lead content. Attention is called to the fact that no definite relationship has yet been found between hardness and resistance to pounding. Alloys of the same hardness may differ in resistance to pounding, while alloys of different hardnesses may have the same resistance to pounding.

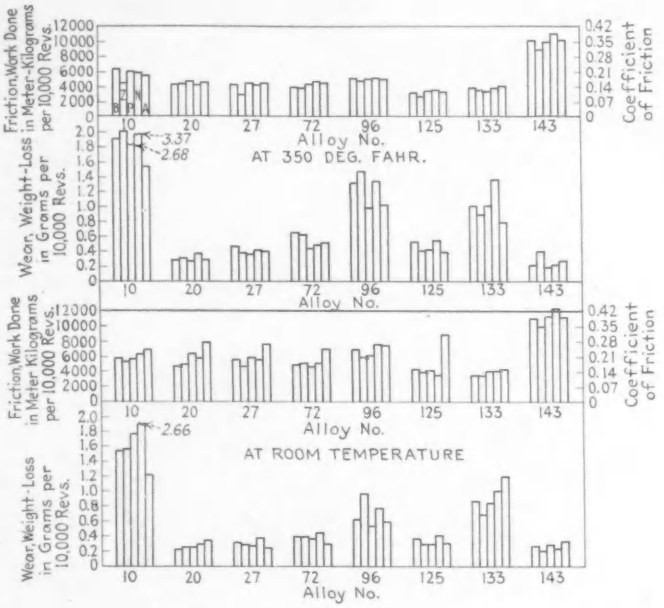
A comparison of the various properties determined on the copper-tin-lead bronzes with and without additions of zinc, 4 per cent; phosphorous, 0.05 per cent; nickel, 2 per cent and antimony, 1 per cent is given in Figs. 8, 9, 10 and 11.

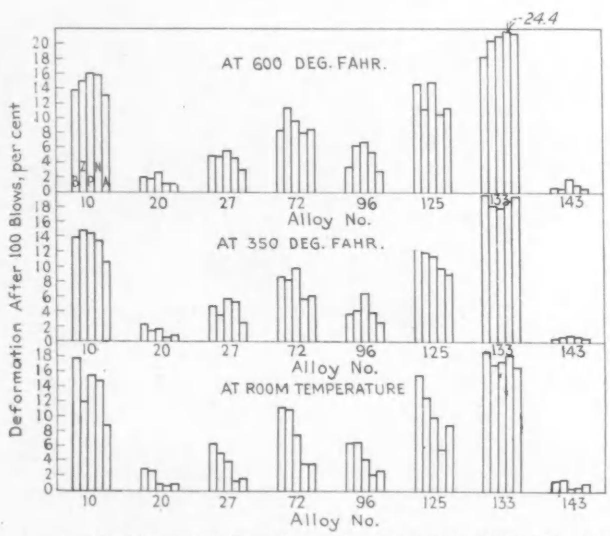
Results with Zinc Addition of 4 Per Cent

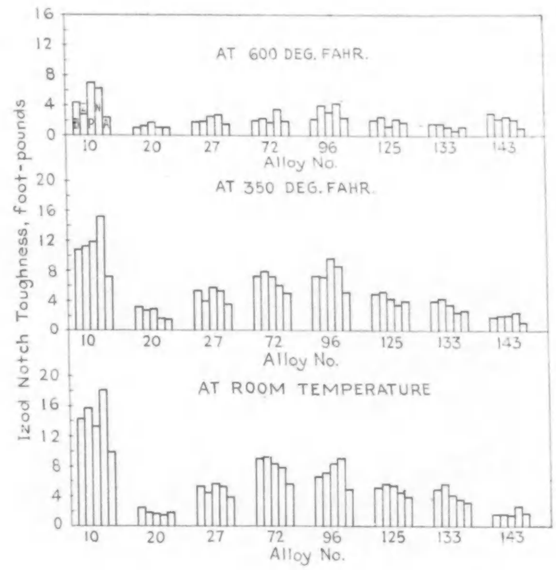
Zinc is frequently added to copper-tin alloys as a deoxidizer, to improve their soundness. The constitution and mechanical properties of these alloys, known as copper-rich kalchoids, have been determined by a number of investigators, S. I. Hoyt[14], L. Guillet[15], L.

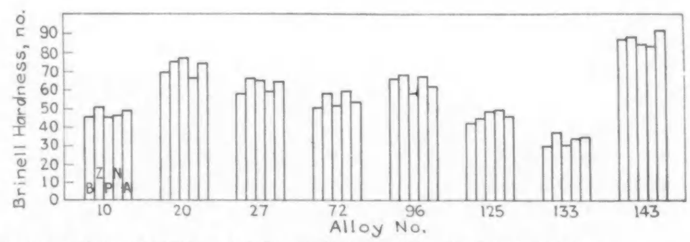
[14] See *The Journal of the Institute of Metals*, vol. 10, 1913, p. 235.

[15] See *Revue de Métallurgie, Mémoirs*, May, 1906, p. 243.









COMPARISONS OF CHARACTERISTICS OF BRONZES WITH AND WITHOUT ADDITIONS

Each Group of Five Rectangles Represents a Certain Characteristic of Five Different Bronzes. The Rectangle at the Left in Each Group, Marked B in the First Group, Represents the Basic Alloy of the Number Indicated Below the Group. The Other Rectangles in the Same Group Represent Corresponding Bronzes with the Additions under Investigation, the Order in Each Group Being as Represented in the Following Table. Where the Rectangle Should Extend beyond the Scale, Its Correct Height Is Indicated by Figures

Order in Which Alloys Are Grouped in Charts

Rectangle	1	2	3	4	5
Marked	B	Z	P	N	A
Addition	Basic	Zinc	Phosphorus	Nickel	Antimony
Per Cent	None	4	0.05	2	1

FIG. 8—WEAR CHARACTERISTICS AT ROOM TEMPERATURE AND AT 350 DEG. FAHR.

FIG. 9—RESISTANCE TO REPEATED POUNDING, AT ROOM TEMPERATURE AND AT 350 AND 600 DEG. FAHR.

FIG. 10—RESISTANCE TO IMPACT AT THE THREE TEST TEMPERATURES

FIG. 11—BRINELL HARDNESS OF THE VARIOUS ALLOYS TESTED

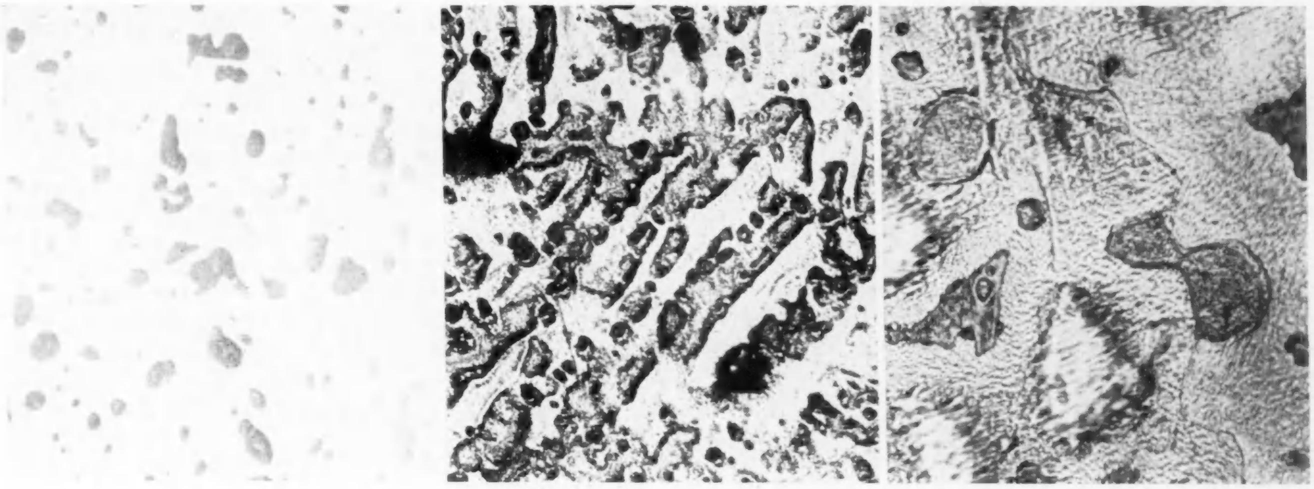


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FIG. 12—MICROSTRUCTURE OF 80-10-10 BRONZE WITHOUT ADDITIONS

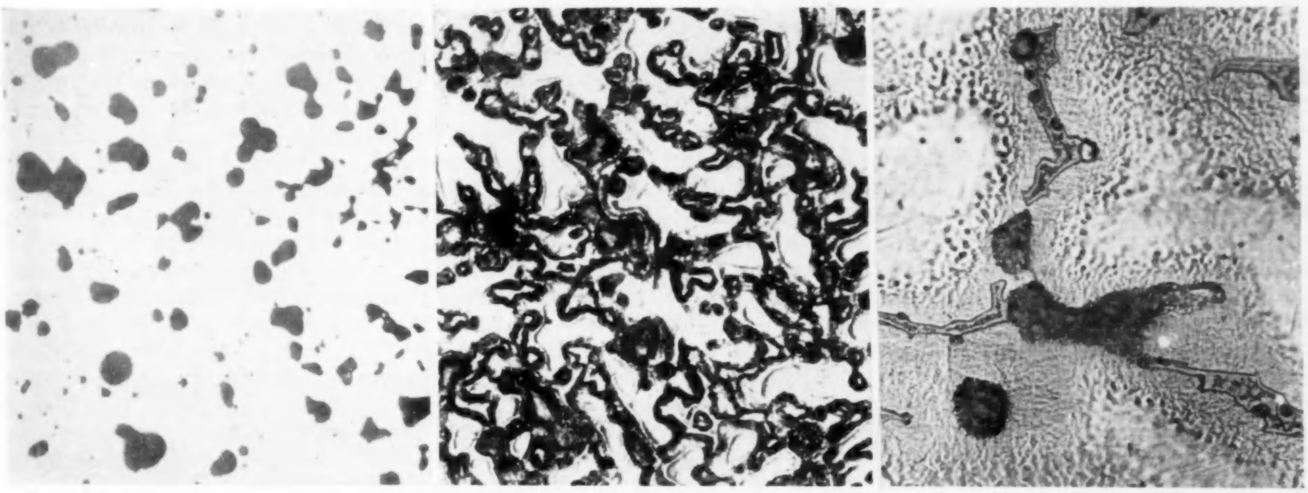

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FIG. 13—MICROSTRUCTURE OF 80-10-10 BRONZE WITH ADDITION OF 4 PER CENT OF ZINC

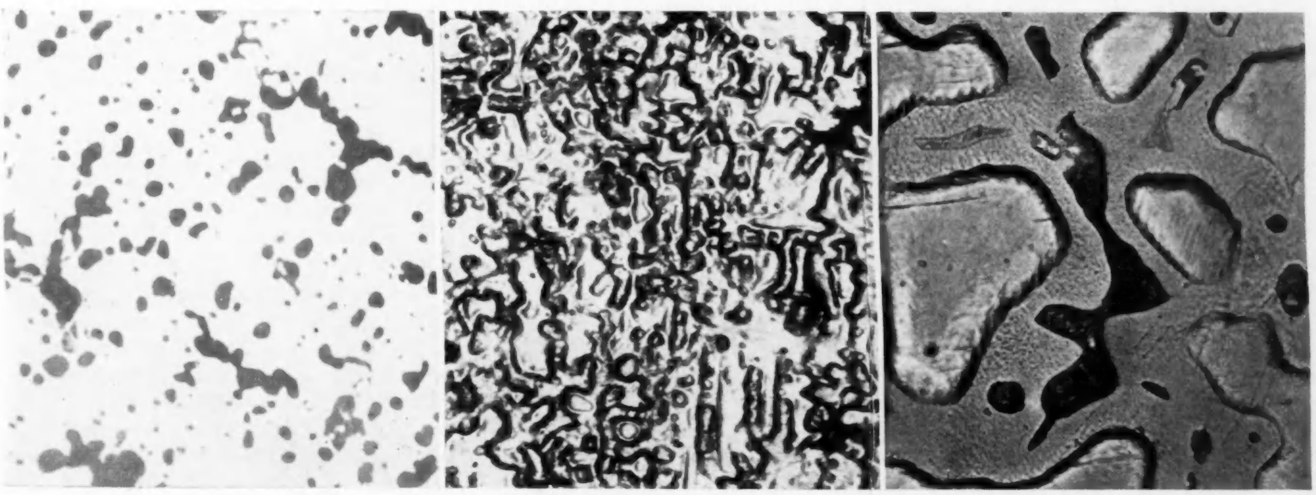

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FIG. 14—MICROSTRUCTURE OF 80-10-10 BRONZE WITH ADDITION OF 0.05 PER CENT OF PHOSPHORUS

Guillet and L. Revillon[16], R. H. Thurston[17] and Hanns v. Miller[18]. Portevin and Nusbaumer[19] have reported results from a Derihon machine and found that bronze alloys containing about 2.5 per cent of zinc with 5 to 10 per cent of tin had higher wear-resistance than alloys without zinc but having tin contents of 13 to 19 per cent.

Structure.—Micrographs were made to show the effects on the structure of the additions investigated. Fig. 12 shows the alloy of copper, 80 per cent; tin, 10 per cent and lead, 10 per cent. In this and the other groups of three micrographs, the one at the left is of an unetched section and the central one is of an etched specimen, both with a magnification of 100 times; and the micrograph at the right is of an etched specimen, magnified 500 times.

Adding 4 per cent of zinc to the base alloy produced no change in either the distribution or the segregation of lead, as is seen by comparing the unetched sections shown at the left in Figs. 12 and 13. A comparison of the middle portions of the same figures shows that the addition of 4 per cent zinc increased the relative amount of the eutectoid constituent, alpha and delta, over that of the alloy without additions. The increased amount of the eutectoid constituent in the zinc alloys probably accounts for the fact that the wearing-in period of the specimens in the Amsler test was longer than in the case of the base alloy of only copper, tin and lead.

Wear Resistance.—In a previous paper[6], the effects produced on a number of bearing bronzes by the addition of 4 per cent of zinc have been discussed in detail. In the present investigation, the rate of wear at room temperature of alloy containing 4 per cent of zinc was about the same as that of the alloys containing no added impurities, with the exception of alloy No. 96. In this alloy, basically 88 per cent copper, 10 per cent tin and 2 per cent lead, the addition of 4 per cent of zinc caused an increase of about 53 per cent in the wear rate at room temperature but only 12 per cent at 350 deg. fahr. (175 deg. cent.) With the exception of alloy No. 96, and perhaps No. 133, it may be said that the addition of 4 per cent of zinc has no appreciable effect on the wear resistance or the frictional forces between the copper-tin-lead alloys and steels.

Repeated Pounding.—The addition of 4 per cent of zinc increased the resistance of the alloys to pounding at room temperature but had little effect at temperatures of 350 deg. fahr. At 600 deg. fahr. (315 deg. cent.) however, the tendency was toward decreased resistance to pounding. Some of the alloys containing zinc showed less deformation at the end of 100 blows than the companion alloys containing no zinc. In other cases, greater deformation was obtained with the alloys containing zinc. The differences, however, were slight and for practical purposes it may be stated that the addition of 4 per cent of zinc has little effect on the resistance to deformation.

Resistance to Impact.—The addition of 4 per cent of zinc had a tendency to increase the resistance to impact of the alloys studied, at both room temperature and elevated temperatures.

Brinell Hardness.—Of the alloys studied, those with zinc were consistently harder than those without zinc. The increase in hardness attributable to the addition of 4 per cent of zinc was slight, however.

In some respects, the results previously reported confirm those of G. H. Clamer[20] who found that the addition of zinc to leaded bronzes hardens the alloys and increases the wear rate, but he concluded that the alloys having approximately 5 per cent of tin, up to 20 per cent of lead and up to 5 per cent of zinc should be entirely satisfactory for all classes of car-journal bearings.

Results with Phosphorus Addition of 0.05 Per Cent

Phosphorus is frequently added to deoxidize bronze It is generally added as phosphor-copper, although stick phosphorus is sometimes used. Phosphor-bronze occasionally contains as much as 1 per cent of phosphorus. Bronzes containing about 0.7 per cent of phosphorus have been reported to have desirable mechanical properties, by A. Philip[21] and others.

Structure.—The addition of 0.05 per cent of phosphorus to the base alloy of 80 per cent copper, 10 per cent tin and 10 per cent lead appears to minimize the segregation of lead, as can be seen by comparing the left portions of Figs. 12 and 14. Comparison of the center portions of the same figures shows that the grain size of the alloys containing 0.05 per cent of phosphorus is finer than that of the alloys without phosphorus. This finer grain size may be largely responsible for the increased Brinell hardness and increased resistance to wear which was found for these alloys.

Wear Resistance.—In general, the addition of 0.05 per cent of phosphorus was found to increase slightly the wear resistance but not appreciably to affect the frictional force. Most of the alloys containing phosphorus showed higher wear resistance both at room temperature and at 350 deg. fahr., than the base alloy. However, alloy No. 10, basically 96 per cent copper, 2 per cent tin and 2 per cent lead, showed the addition of phosphorus to be deleterious at both temperatures.

Repeated Pounding.—All of the alloys tested showed a consistent and appreciable effect of phosphorus in the resistance to pounding. At room temperature this effect was to increase the resistance to deformation, at 350 deg. fahr. there was little effect, and at 600 deg. fahr. there was a reduction in the resistance to deformation.

Resistance to Impact.—The addition of 0.05 per cent of phorphorus had no marked effect on the notch toughness at either room temperature or 350 deg. fahr. At 600 deg. fahr., there was a tendency toward a slight increase in toughness.

Brinell Hardness.—Of the eight alloys, with and without phosphorus, which were tested, six showed a slightly increased hardness due to the phosphorus addition, while two showed the opposite influence. The magnitude of the effects found was not great; so it may be said that the phosphorus addition has little effect on the Brinell hardness, although the tendency seems to be toward an increase in hardness.

The results from the tests with bronzes which contained nickel were somewhat analagous with those of

[16] See *Revue de Métallurgie*, June, 1910, p. 429.

[17] See Brasses, Bronzes, and Other Alloys and Their Constituent Metals, by R. H. Thurston, fourth edition, John Wiley & Sons, p. 172.

[18] See *Metallurgie* (German), Jan. 22, 1912, p. 63.

[19] See *Revue de Métallurgie*, February, 1912, p. 61.

[20] See *Transactions of the American Institute of Metals*, vol. 9, 1915, p. 241.

[21] See *The Journal of the Institute of Metals*, vol. 1, 1909, p. 164.

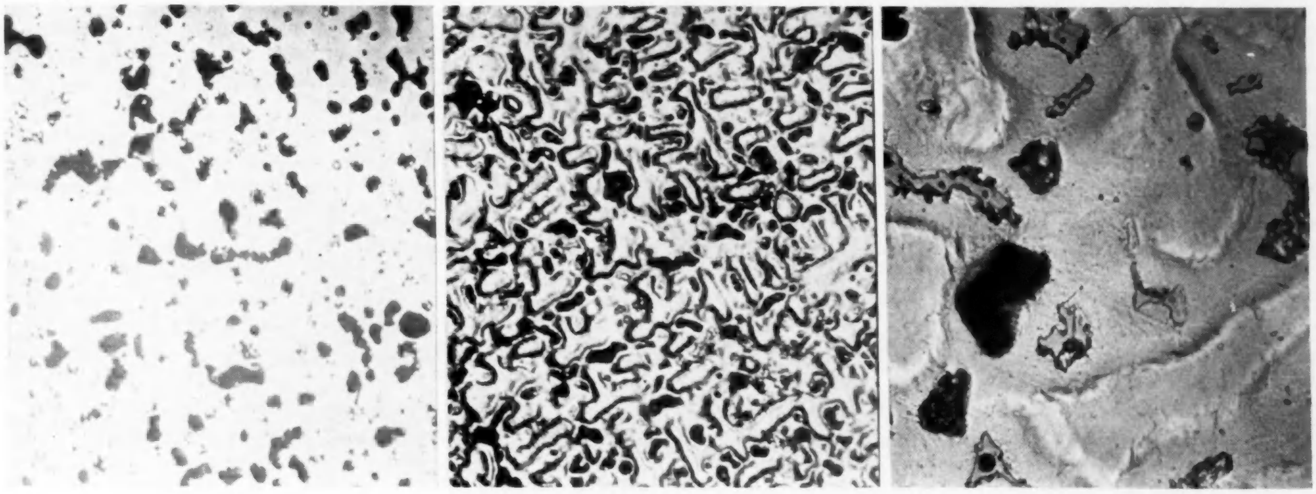

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FIG. 15—MICROSTRUCTURE OF 80-10-10 BRONZE WITH ADDITION OF 2 PER CENT OF NICKEL

W. M. Corse[22], who has reported that the tensile strength and elongation of 80-10-10 bronze is improved by the addition of 1 per cent of nickel. He has further stated that nickel additions also increase the rate of cooling and thereby reduce to the minimum the tendency toward lead segregation.

Structure.—The alloys containing 2 per cent of nickel showed a finer distribution, less segregation of the lead, and also a finer grain size than the comparison alloys containing no nickel. These conditions can be observed by inspection of Figs. 12 and 15. It should be noted from the right portion of Fig. 15, that the eutectoid constituent of the nickel alloy was comparatively free from alpha and occurred frequently in direct contact with lead particles. This may account in part for the higher frictional forces and the decrease in wear resistance.

Wear Resistance.—All alloys containing 2 per cent of nickel—with the exception of No. 143, having a base composition of 85 per cent copper and 15 per cent tin—showed increased wear-rates at room temperature. At 350 deg. fahr., alloys Nos. 27 and 96 gave results indicating a slighly beneficial effect of nickel. Alloy No. 27 contains copper, 80 per cent; tin, 10 per cent and lead, 10 per cent. Alloy No. 96 contains copper, 88 per cent; tin, 10 per cent and lead, 2 per cent. In general, the addition of 2 per cent of nickel increased the wear rate of the alloys and slightly increased the frictional force, as indicated by measurements with the torque indicator.

Repeated Pounding.—A noteworthy advantage gained by the addition of 2 per cent of nickel is apparent from the results of the pounding tests at room temperature. With the exception of those alloys very low in tin, Nos. 10 and 133, the nickel addition increased the resistance to deformation of the alloys about 300 per cent. At 350 deg. fahr., the beneficial effect of nickel was not as apparent as at room temperature, and there was no beneficial effect at 600 deg. fahr.

Resistance to Impact.—In the alloys containing low amounts of lead, Nos. 10, 96 and 143, the addition of 2 per cent of nickel generally increased the resistance to impact at the three test temperatures, but there was a decrease with alloy No. 143 at the test temperature of 600 deg. fahr. In alloys containing more than 2 per

[22] See *Metal Industry*, June, 1924, p. 234.

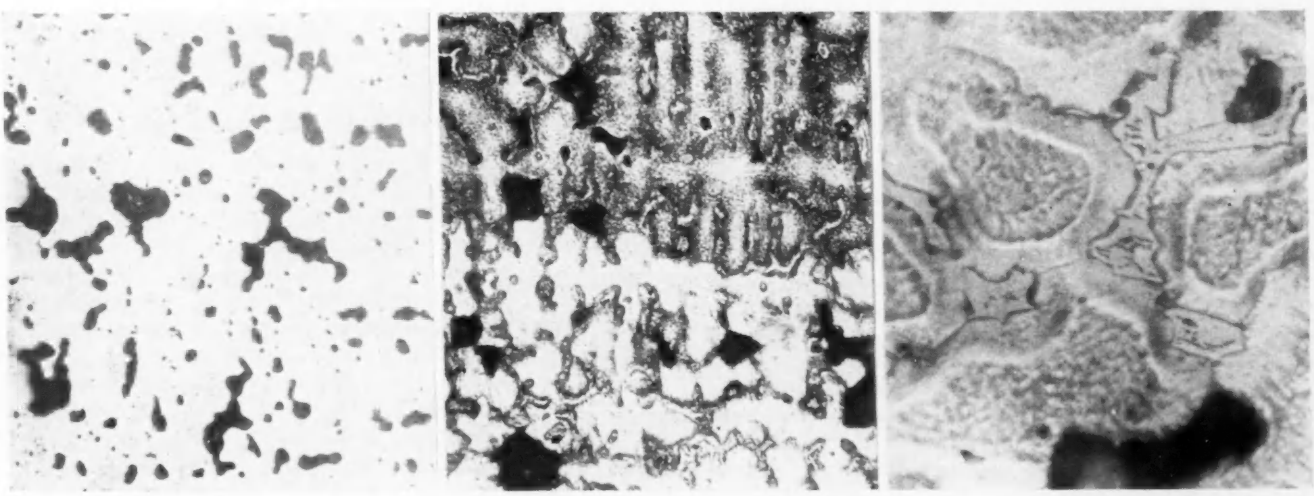

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FIG. 16—MICROSTRUCTURE OF 80-10-10 BRONZE WITH ADDITION OF 1 PER CENT OF ANTIMONY

TABLE 3—GENERAL EFFECTS OF THE ADDITIONS STUDIED ON THE PROPERTIES OF BRONZES

Addition		Wear Resistance (Ambler Test)	Frictional Force	Resistance to Pounding, at			Resistance to Impact (Izod)	Brinell Hardness
Element	Per Cent			70 Deg.	350 Deg.	600 Deg. Fahr.		
Zinc	4	No appreciable effect. Decreased with alloys of low lead and high tin	Not affected	Increased	No appreciable effect	No appreciable effect	Tendency to increased toughness at all test temperatures	Slightly harder
Phosphorus	0.05	Increased in most cases	Not affected	Increased	Little effect	Pronounced decrease	No definite change	Tendency toward slight increase
Nickel	2	Decreased	Slightly increased	Marked increase	Slight increase	Decreased in many cases	Increased with low lead-content; decreased with appreciable lead	No appreciable change
Antimony	1	Increased in most cases	Increased at 70 deg. fahr.	Increased	Increased	Increased	Decreased about 30 per cent	Slightly harder in most cases

cent of lead, the nickel addition in general caused a slight decrease in toughness.

Brinell Hardness.—The addition of 2 per cent of nickel produced no marked effect on the hardness of the alloys studied although there appeared to be a slight tendency toward an increase in hardness.

Results with Antimony Addition of 1 Per Cent

Antimony is nearly always considered an undesirable impurity in bronze. It has been stated, however, by R. T. Rolfe[23] that antimony frequently occurs in gun metal, sometimes to the extent of 1 per cent, and that gun-metal castings containing from 0.5 to 1 per cent antimony show no marked falling off in the mechanical properties. In a later publication, however, the same author[24] has stated that the effect of higher percentages of antimony is to increase progressively the hardness and brittleness and to cause a progressive falling off in the strength and ductility. No difference in soundness or microstructure was reported.

Structure.—In the alloys studied, the addition of 1 per cent of antimony to the base alloy of 80 per cent copper, 10 per cent tin and 10 per cent lead appeared to increase the segregation of lead, as shown by a comparison of the unetched micrographs in Figs. 12 and 16. The addition of antimony did not appear to affect the general grain size of the alloy. It is probable that the antimony is largely alloyed with the lead and results in a lower wear-resistance as compared with the base alloy without antimony. Comparison of the etched micrographs in Figs. 12 and 16 shows this condition.

Wear Resistance.—Although the addition of 1 per cent of antimony in many instances increased the wear resistance of the alloys studied, it also increased the friction. At room temperature, the indicated friction of the alloys containing antimony was considerably higher than of those without antimony. This effect was not so noticeable at 350 deg. fahr. as at room temperature.

Repeated Pounding.—A beneficial effect in resistance to pounding was produced by 1 per cent of antimony. Increases as high as 300 per cent were noted at room temperature, and the advantage gained by adding antimony was still apparent at 350 and 600 deg. fahr.

Resistance to Impact.—Probably the most definite effect of antimony was to decrease resistance of the copper-tin-lead alloys to impact. In most of the alloys studied at the three test temperatures, the addition of 1 per cent of antimony reduced the resistance to impact about 30 per cent.

Brinell Hardness.—The addition of 1 per cent of antimony had little effect on the hardness of the alloys studied, although there seemed to be a tendency toward an increase in hardness.

Summary

The results of the effects of different additions on the properties of bearing bronzes are briefly summarized in Table 3.

THE DISCUSSION

DR. R. L. DOWDELL:—When a bronze bearing is run without lubricants and the metal begins to flow, the lead in the bronze acts to some extent as a lubricant.

CHAIRMAN H. T. WOOLSON[25]:—Bronze is still used in a few places on powerplants, and rather important places at that. It would be very helpful if the bronze manufacturers would lay down rules to guide engineers in selecting the correct material for the job.

When I started in marine-engine work, some 30 years ago, the general manager used to swear by 88-10-2 bronze, but evidently 80-10-10 is the normal proportion now.

DR. DOWDELL:—Not for everything, but for many purposes.

Oil Film Must Be Maintained

DR. CARL CLAUS[26]:—Dr. Dowdell's remarks seem to indicate that he would be a great deal happier if our ultimate goal were to get a bearing alloy which would function in contact with the shaft without an oil film, but I do not think any one of us is optimistic enough to consider that a possibility. Under ordinary operating conditions, bearing material is separated from the shaft by an oil film, and we all know that our bearings are about gone when this oil film breaks down. So our ultimate aim is to make a bearing which will always maintain such an oil film. It is doubtful that lead will produce anything which will replace the oil film.

This oil film must be maintained largely by providing a suitable bearing structure to which the oil can cling, and there are several ways of providing such a struc-

[23] See *The Journal of the Institute of Metals*, vol. 20, 1918, p. 263.

[24] See *The Journal of the Institute of Metals*, vol. 24, 1920, p. 233.

[25] M.S.A.E.—Chief engineer, Chrysler Corp., Detroit.

[26] M.S.A.E.—Research engineer, Bound Brook Oil-less Bearing Co., Bound Brook, N. J.

ture. Certain alloys which we are accustomed to call bearing alloys, or bearing metals, accomplish this purpose of providing a suitable foothold for the oil.

Making a bearing which consists of a porous structure is another way of improving this condition. The conventional method of making a bearing is to melt an alloy in the foundry and make a casting such as those used in this investigation. But there is another method of producing an alloy, which consists in mechanically mixing finely pulverized metals, such as copper and tin, and compressing them, possibly separated by a small percentage of graphite, heat-treating the mixture afterward, and producing an alloy at a temperature below the melting point of copper. This is an alloy just as truly as the molten alloy, and it provides a porosity in the bearing of, let us say, 25 per cent. This porosity permits the bearing to absorb oil readily and to retain it.

Comparison of a bearing which has been cast and another one which has been produced synthetically shows the two bearings to give entirely different results. In a spring shackle, for instance, one will show rapid wear, and the other will last for a very much longer time, simply because the oil film keeps the bolt and the bearing from metal-to-metal contact. While the investigations carried out by these gentlemen are extremely interesting, they do not focus very clearly on our ultimate aim in the bearing industry, which is to provide something that will maintain the necessary oil film under operating conditions such as we find in general practice.

Economy of Synthetic Bearings Questioned

DR. DOWDELL:—Dr. Claus has introduced a question that has been debated much among lubricating engineers, and there is no question that he has told us some things that are both interesting and true. These synthetic bearings are good for light-pressure work, but there is quite a question as to their suitability for heavy pressures. Economics introduces another question; in fact, some of the synthetic alloys are completely hopeless in that respect.

Bearing metal has been defined by a committee of the American Society of Mechanical Engineers[27] as "An alloy that is capable of retaining a lubricant on a bearing surface." That is probably a very good definition. Whether it is composed of hard particles in relief or of soft particles seems to make no appreciable difference. No good bearing alloy, by the way, is of the solid-solution type; they are all materials containing two or more microconstituents. Some solid solutions have been tried and have not been satisfactory.

One explanation of why some bearing materials serve better than others is that small recesses allow the oil to remain in or around them for a short time so that, when the bearing becomes heated and the general film breaks down, some of this oil may be volatilized and act as a lubricant.

Perhaps the ideal condition is to have the graphite impregnated within the copper-tin matrix, but that is hard to do economically. Graphitometal-France is the name of a new bearing metal that has been used in France. It is composed of a white metal into which graphite is introduced under pressure. The ingredients are simply mixed and extruded by a press, and the metal is claimed to give very good results with no after treatment.

DR. CLAUS:—The economic question was mentioned. Powdered material for bearings such as I have described is more expensive than the metal that is bought for foundry use; but the bearings are compressed on automatic machines to extremely close limits, no grinding, turning or boring is required, and all hand labor is eliminated. The bores and outside diameters are ordinarily manufactured to limits of plus or minus 0.0005 in., and I know of one which is made with eccentricity limits kept to 0.001 in. by dial inspection. Those bearings are made to length limits of plus or minus 0.005 in. Another consideration is that about 25 per cent less metal by weight is required than for cast bearings. In these ways the higher unit cost of the powdered metal is offset somewhat, and in many cases entirely, by the savings in labor and in weight of material.

DR. DOWELL:—How does the material that you have described stand up under pounding? Is it annealed so the matrix is especially solid?

Crystals Form under Pressure

DR. CLAUS:—The structure is exactly the same as is obtained in a casting. Microphotographs reveal twin crystals and other typical crystal structures.

DR. DOWDELL:—Is the annealing temperature high enough to form crystals?

DR. CLAUS:—The heat-treatment is at a temperature of approximately 1500 deg. fahr., which produces the same mechanical characteristics as if the metal were melted and cast. Facts in my possession demonstrate that synthetic bearings have actually withstood much higher pressure than cast bearings, and the only way this can be explained is by assuming that the oil film is always maintained at the point of contact.

DR. DOWDELL:—That is the point. If the oil film is not maintained, small amounts of graphite or lead or some such material are needed.

DR. CLAUS:—I did not intend to say so much about this particular type of bearing. The point I want to bring out is that we ought to direct our efforts toward maintaining the oil film, and that this can be done either by providing a structure in the conventional type of casting suitable to maintain an oil film or by providing a porous structure containing oil and giving a better chance for the oil to adhere.

GEORGE H. ADAMS[28]:—One point mentioned in this paper I believe is of prime importance and should be given careful thought by all engineers interested in bearing design; that is the extremely large number of special alloys now specified by automotive engineers.

The company I represent is now making over 100 bronzes of different analyses for the automotive industry and some 50 additional alloys for other fields. In most cases, the specifications call for a metal analysis slightly different from our own or S.A.E. standards, necessitating special mixes and a higher cost to the purchaser.

Unfortunately, bearing manufacturers are seldom consulted when material specifications are drawn. We believe that, if our recommendations were requested on new designs or contemplated changes, the result would be a considerable saving in cost to the industry and the adoption of bronzes having a lower wear rate and longer life in many cases.

[27] See *Mechanical Engineering*, June, 1919, p. 538.

[28] M.S.A.E.—Director of sales, Bunting Brass & Bronze Co., Toledo, Ohio.

Atmospheric Conditions and Knock Testing[1]

By D. B. Brooks[2], N. R. White[3] and H. H. Allen[3]

Annual Meeting Paper — *Illustrated with* Photographs and Charts

THIS paper constitutes a progress report on work undertaken with the object of ascertaining the order of magnitude of the errors likely to be introduced in knock testing by variations in atmospheric conditions.

The atmospheric factors studied were barometric pressure, air temperature and humidity. The latter two were controlled, the effect of barometric pressure being studied as opportunity arose. The effects of these factors on both absolute and relative detonation of fuels were studied, ratings being obtained in terms of benzol and of tetraethyl lead in straight-run Pennsylvania-base gasoline and in terms of iso-octane in normal heptane in some cases.

The results show that normally the effects of humidity and barometric pressure are small and that air temperature should be maintained reasonably constant.

THE effects of atmospheric conditions on some phases of engine testing have long been recognized, and appropriate corrections have been determined for reducing the observed data to standard conditions. Until recently, however, the precision of detonation-test methods has not been such as to justify a study of the effects of atmospheric conditions on knock testing.

In connection with the Cooperative Fuel Research Detonation Subcommittee's program, the Bureau of Standards has undertaken to study these effects, with a view to determining which atmospheric factors may be neglected, and which factors must be controlled or corrected to standard values. This paper constitutes a preliminary report of this work. The object of this report is to indicate the order of magnitude of the errors likely to be introduced in knock ratings by variations in atmospheric conditions.

Atmospheric Factors

The atmospheric factors deemed of sufficient importance in connection with knock testing to warrant study are air pressure, air temperature and humidity. It is well known that each of these factors affect the "absolute" intensity of detonation of a given fuel, under otherwise constant conditions. It is desirable to know quantitatively the effect of each of these factors on the absolute detonation of fuels, in order to know how much variation may be tolerated in atmospheric conditions during a test, without seriously affecting the results. For purposes of knock testing, however, it is also necessary to know whether these factors influence the "relative" detonation of one fuel with respect to another, or with respect to a reference fuel, in order to know whether tests made under different atmospheric conditions are comparable. For example, if today we find a certain fuel equal to 32-per cent benzol in our reference fuel, then under tomorrow's different barometer, temperature and humidity conditions, will it still equal 32-per cent benzol? If not, is the difference to be ascribed to a change in the detonation-suppressing value of the benzol, or to a change in the detonation characteristics of the reference fuel, or of the test fuel?

The three things to be determined may be broadly outlined by the questions:

(1) What atmospheric factors, if any, vary sufficiently to affect the absolute detonation of a given fuel over short periods of time such as would elapse between successive tests in a detonation determination?

(2) What atmospheric factors, if any, vary sufficiently to affect the relative detonation of a given set of fuels over periods of days, weeks or months which may elapse between duplicate tests?

(3) What are the magnitudes of the effects produced by either normal or extreme differences in atmospheric conditions?

The normal and the extreme magnitudes of variation of the atmospheric factors are naturally of interest in this connection. For stations at altitudes between sea level and 1100 ft. the normal barometric range is from 715 to 785 mm. (28.15 to 30.91 in.) of mercury. Under extreme conditions, this range may be as large as from 680 to 800 mm. (26.77 to 31.50 in.) of mercury. Inasmuch as knock testing is normally done indoors, the temperature range differs from that of the free atmosphere and may be estimated as within the limits of from 5 to 55 deg. cent. (41 to 131 deg. fahr.) except in the case of artificially heated air. Humidity, expressed herein as pressure of water vapor, normally is but slightly higher indoors than in the free atmosphere and may thus vary from less than 1 to 60 mm. (0.039 to 2.36 in.) of mercury or possibly more.

In these preliminary tests, it was not possible to explore completely these ranges of conditions. Barometric pressure varied from 748 to 772 mm. (29.45 to 30.39 in.) of mercury; intake-air temperature was varied from 20 to 57 deg. cent. (68 to 134.6 deg. fahr.) and humidity from 7 to 48 mm. (0.276 to 1.89 in.) of mercury. It is intended later to extend these ranges to the extreme limits stated above.

[1] Publication approved by the Director of the Bureau of Standards of the Department of Commerce.

[2] S.M.S.A.E.—Automotive engineer, Bureau of Standards, City of Washington.

[3] Assistant engineer, Bureau of Standards, City of Washington.

Apparatus and Procedure

The test apparatus shown in Fig. 1, consisted of a Cooperative Fuel Research detonation-test engine[4] coupled to a direct-current electric-dynamometer. In all tests, detonation was estimated by use of the bouncing-pin apparatus.[5] The latter apparatus was of the most recent design, the pin resting on a diaphragm exposed to the cylinder pressure.

Air was conditioned in the vertical tube at the extreme right of Fig. 1, temperature being controlled by passing steam or water of suitable temperature through spirals of copper tubing within the conditioning cylinder and humidity being controlled by the injection of dry steam. Subsequent to this conditioning, the air passed over a series of six baffles, to insure homogeneity. Temperature and humidity were measured by continuously passing part of the air supply over dry and wet-bulb thermometers graduated to 0.2 and 0.1 deg. cent. (0.36 and 0.18 deg. fahr.) respectively. This air sample was then rejected, as its humidity had been increased materially during passage over the wet bulb.

The Ferrel psychrometric formula used for calculation of humidity is

$$e = e_1 - 0.000660\, B\, (t - t_1)\, (1 + 0.00115\, t_1)$$

in which

B = barometric pressure in inches of mercury
e = pressure of water vapor at t and t_1
e_1 = vapor pressure of water at t_1
t = dry-bulb temperature in degrees centigrade
t_1 = wet-bulb temperature in degrees centigrade

For convenience in determining humidity, a chart such as is shown in Fig. 2, which is based on the Ferrel formula, is used. To use this chart, place a straight edge so that it intersects the scale at the left at the value of the difference between wet and dry-bulb readings and intersects the center scale at the value of the wet-bulb temperature. Extend to the intersection with the vertical line representing the barometric pressure and read humidity in the units shown on the slanting scale at the right.

For convenience a nomogram for correcting the barometer reading for temperature is included, this being placed at the lower right of the chart. To find the barometer temperature-correction, align a straight edge through the center of the small circle near the bottom of the wet scale, and through the value of the observed-barometer temperature on the vertical scale marked BAR. TEMP. Extend, as in the case of the humidity nomogram, to the intersection with the vertical line representing the observed barometer-reading and read the temperature correction to the barometer on the same slanting scale used for humidity correction. This reading in millimeters is to be subtracted from the observed barometer-reading to give true atmospheric-pressure. This correction chart is for barometers having brass scales.

The usual constant 0.000660 of the Ferrel formula was found not to apply for the psychrometer used in these tests. The apparatus was calibrated in place under operating conditions, the value found for the constant being 0.00075.

In evaluating the relative detonation of fuels, the

[4] See *Proceedings of the American Petroleum Institute*, Jan. 2, 1930, p. 32.

[5] See THE JOURNAL, January, 1922, p. 8.

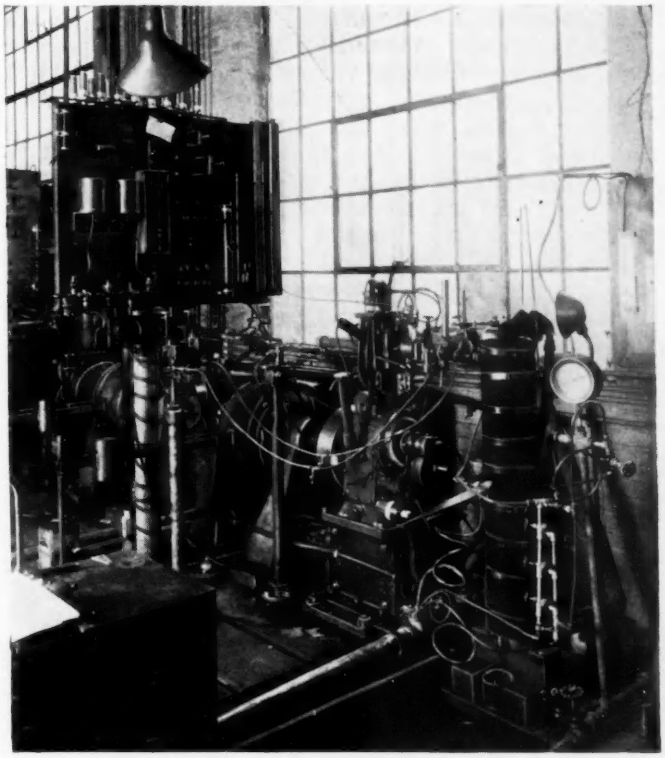


FIG. 1—COOPERATIVE FUEL RESEARCH DETONATION-TEST ENGINE

Apparatus for Air Conditioning Is Shown at the Extreme Right

Cooperative Fuel Research Detonation Subcommittee's tentative procedure was used. This method differs from customary methods principally in the emphasis laid on precise adjustment of mixture ratio for each fuel, considering each blend with benzol as a different fuel, to that giving maximum intensity of detonation.

The method for making the carbureter adjustment when using the bouncing-pin is illustrated in Fig. 3. It consists in taking gas-evolution readings at not less than five mixtures-ratios in the region near maximum intensity of detonation, plotting these readings against carbureter setting, and, from the plot, estimating the exact setting for maximum knock. The vertical line somewhat to the left of the median of the curve shown in Fig. 3 is the setting for maximum intensity as estimated by the Cooperative Fuel Research audibility method. This method consists in setting for just audible knock and noting the rich and lean limits of detonation. These should differ by not more than 0.5 mixture-ratio. The middle point of the range is then chosen as the correct setting for maximum knock.

TABLE 1—CONTROLLED FACTORS IN TESTS

Engine Speed	600 r.p.m. ± 5 r.p.m.
Compression Ratio	5.50
Cylinder and Manifold Jackets Temperature	98 to 100 deg. cent. (208.4 to 212 deg. fahr.)
Oil Temperature	55 to 60 deg. cent. (131 to 140 deg. fahr.)
Air Temperature	±1 deg. cent. (1.8 deg. fahr.)
Humidity	±1 mm. (0.039 in.) of mercury
Throttle Opening	Fixed
Carbureter Adjustment	Fixed
Spark Advance	Fixed at 12 deg.

During any fuel comparison, all conditions were held as nearly constant as practicable. Controlled factors with their ranges or limits of variation are given in Table 1.

In determining the quantity of tetraethyl lead or benzol which must be added to the base fuel to give detonation equal in intensity to that of a given test-fuel, readings were taken of the gas evolved in the eudiometer of the bouncing-pin apparatus when operating on the test fuel and when operating on blends of the base fuel with quantities of benzol or tetraethyl lead giving greater and smaller gas evolutions. By interpolation, the quantity of benzol or tetraethyl lead which must be added to the base fuel to give gas evolution equal to that with the test fuel was estimated.

Five fuels were used in this work, the Cooperative Fuel Research Pennsylvania base fuel being used as a reference. The others are listed in Table 2.

The Effect of Humidity on Relative Detonation

The lead and benzol equivalents of each of the four test-fuels were determined at each of two humidities. The term "lead equivalent," as used in this paper, is defined as the milliliters of tetraethyl lead which must be added to a gallon of the reference fuel to make the intensity of its detonation equal to that obtained when using a given test-fuel, tests of both fuels being conducted under comparable procedure and conditions.

TABLE 2—DATA ON TEST FUELS

Fuel No.	Description
1	50 per cent Cabin Creek gasoline plus 50 per cent California Aviation gasoline
2	U. S. Motor Gasoline
3	California Aviation gasoline
4	Cracked gasoline

The definition of the term "benzol equivalent" is entirely analogous to the above, substituting for milliliters of tetraethyl lead per gallon of the reference fuel, per cent by volume of benzol in a blend with the reference fuel.

In each of these series of tests, all conditions other than humidity were held closely constant. To allow a wider range of humidity, intake air was heated to 40 deg. cent. (104 deg. fahr.). Tests were made at about 7 and at over 40 mm. (0.276 to 1.57 in.) of mercury pressure of water vapor. The results are illustrated in Figs. 4 and 5 and are tabulated, together with relevant data, in Table 3.

In Fig. 4 no significant difference is seen in the anti-

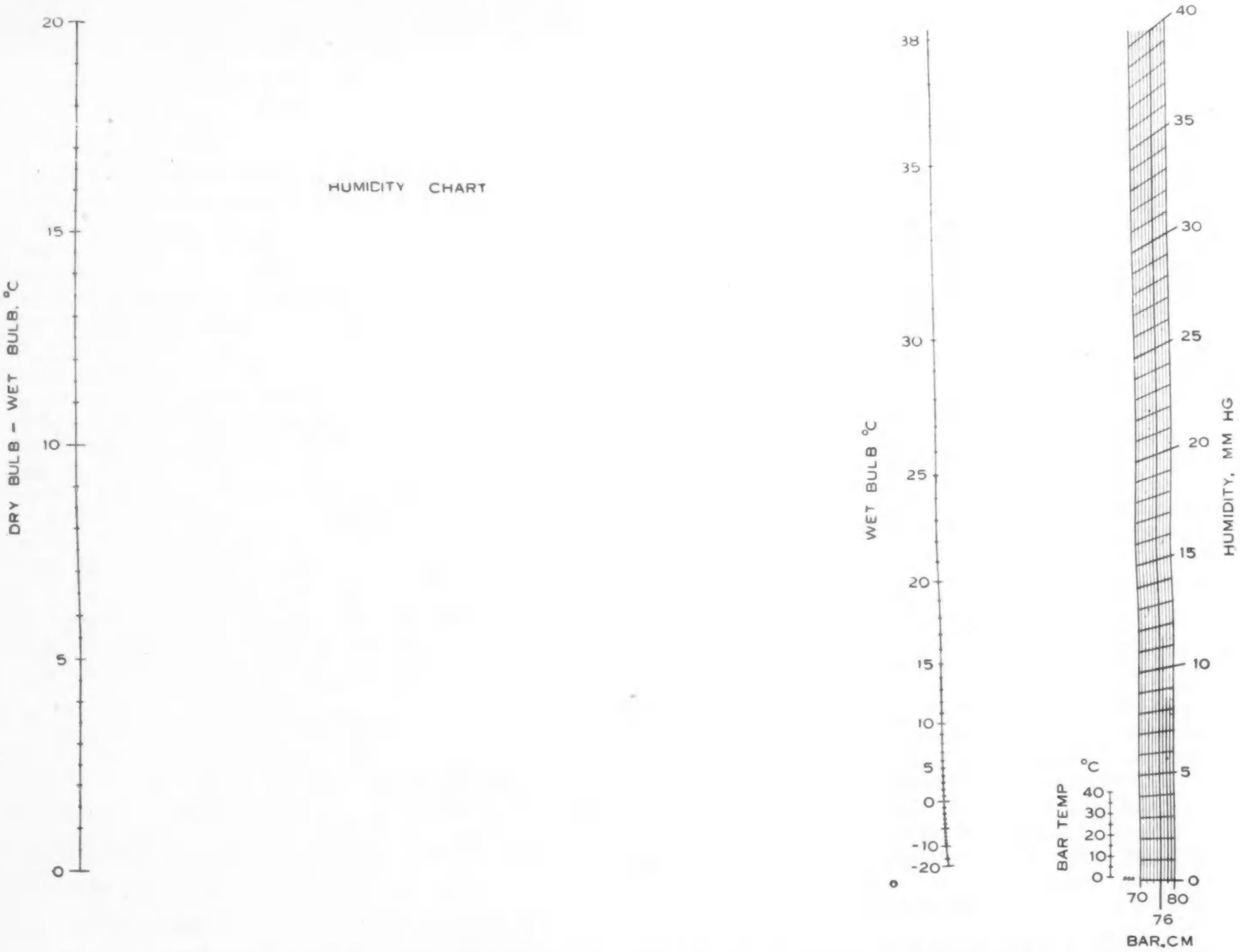


Fig. 2—Nomogram for Obtaining Humidity from Wet and Dry-Bulb Temperatures and Barometric Pressure

In This Chart Temperatures Are in Centigrade Degrees and Pressures in Millimeters of Mercury

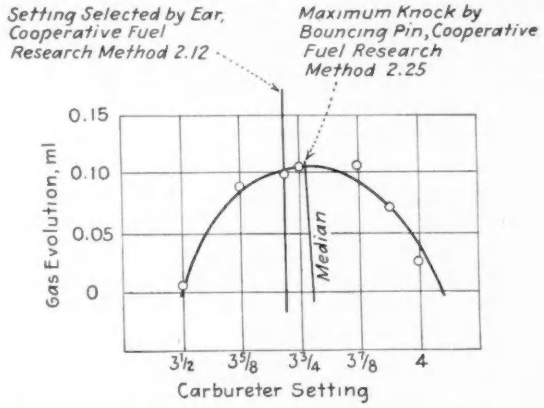


FIG. 3—INTENSITY OF DETONATION VERSUS CARBURETER SETTING

This Curve Illustrates the Cooperative Fuel Research Method for Obtaining Carbureter Setting for Maximum Intensity of Detonation When Using the Bouncing-Pin Apparatus

knock ratings of Fuels Nos. 1 and 2 at different humidities, although in each case a slightly higher benzol-content in the reference fuel is required to match the test fuels at high humidities.

In the case of Fuel No. 3, the first rating at the lower humidity was thought to be erroneously low; however, a duplicate test several weeks later verified the original value within 0.8 per cent. As shown in Fig. 4, a slight increase in benzol content is required at the higher humidity in the case of each of the four fuels. For this increase in humidity, amounting to about 35 mm. (1.38 in.) of mercury, the corresponding increase in benzol content is less than one-twentieth of the original value of the benzol equivalent.

Fig. 5 shows that the lead equivalents of all four fuels decrease with increasing humidity. The lead equivalents at a humidity of 10 mm. (0.394 in.) of mercury are found to have a nearly constant ratio to those at 40 (1.57 in.) of mercury. If this relationship is not accidental, it must be attributed to an increase in the effectiveness of tetraethyl lead when the humidity is increased.

The average value of this ratio is 1.325. Its constancy is illustrated in Table 4. For comparison, the "observed" values are interpolated at humidities of 10 and 40 mm. (0.394 and 1.57 in.) of mercury. In this tabulation, the second and third horizontal rows give the interpolated values of the lead equivalents at 10 and 40 mm. (0.394 and 1.57 in.) of mercury respectively. The fourth row gives the ratio of the values in the second row to those in the third row. This is seen to be reasonably constant. To indicate the magnitude of experimental error which would account for the observed deviations from constant rate of change, the sixth row was computed, showing the values of the lead equivalents at 10 mm. (0.394 in.) of mercury, which would make the percentage change of lead equivalent for the given change of humidity the same for each fuel. The last row shows the difference between these "computed" values and the observed values and indicates the magnitude of the experimental errors necessary to account for the lack of constancy in ratio. These last values are not larger than the probable errors of experiment.

If this result should be found to hold for other fuels and other ranges of humidity, it may be of some importance in connection with the method of action of tetraethyl lead in suppressing detonation. It should be pointed out, however, that the results here presented, since they are based on two points only, do not establish the shape of the curves showing the rela-

TABLE 3—EFFECT OF HUMIDITY ON KNOCK RATING

	Air							
	Humidity,		Temperature,		Barometer,			
Fuel No.	Mm. of Mercury	In. of Mercury	Deg. Cent.	Deg. Fahr.	Mm. of Mercury	In. of Mercury	Benzol in Reference Fuel, Per Cent	Tetraethyl Lead in Reference Fuel, Ml. per Gal.
1	7.0	0.276	40.0	104.0	768	30.236	32.7	...
	33.2	1.307	38.0	100.4	767.5	30.216	32.9	...
	7.05	0.276	40.0	104.0	755.5	29.744	...	1.86
	44.9	1.768	40.0	104.0	757	29.803	...	1.30
2	7.1	0.280	40.1	104.2	765	30.118	30.0	...
	26.2	1.031	40.0	104.0	765	30.118	30.6	...
	48.0	1.890	40.2	104.4	767.5	30.216	30.8	...
	6.25	0.246	40.1	104.2	755	29.724	...	1.65
	45.4	1.787	40.0	104.0	763.5	30.059	...	1.13
3	7.0	0.276	40.1	104.2	768	30.236	53.2	...
	6.9	0.272	40.0	104.0	759.5	29.902	54.0	...
	40.5	1.594	39.5	103.1	767.5	30.216	60.5	...
	6.9	0.272	40.0	104.0	760	29.921	...	9.15
	45.0	1.772	40.0	104.0	756.5	29.783	...	5.95
4	7.0	0.276	40.1	104.2	768	30.236	59.9	...
	42.5	1.673	40.1	104.2	765	30.118	62.9	...
	8.4	0.335	40.0	104.0	760.5	29.941	...	14.6
	44.9	1.768	40.1	104.2	755.5	29.744	...	11.1

TABLE 4—LEAD EQUIVALENTS OF TEST FUELS

Fuel No.	1	2	3	4
Observed Lead-Equivalent at 10 Mm. (0.394 In.) of Mercury	1.61	1.81	8.90	14.45
Observed Lead-Equivalent at 40 Mm. (1.57 In.) of Mercury	1.21	1.37	6.35	11.55
Ratio of Lead-Equivalent at 10 Mm. (0.394 In.) to Same at 40 Mm. (1.57 In.)	1.33	1.32	1.40	1.25
"Computed" Lead-Equivalent at 10 Mm. (0.394 In.) of Mercury Which Would Have the Ratio 1.35 to That at 40 Mm. (1.57 In.)	1.60	1.81	8.42	15.30
Difference between Observed and Computed	+0.01	0.00	+0.48	−0.85

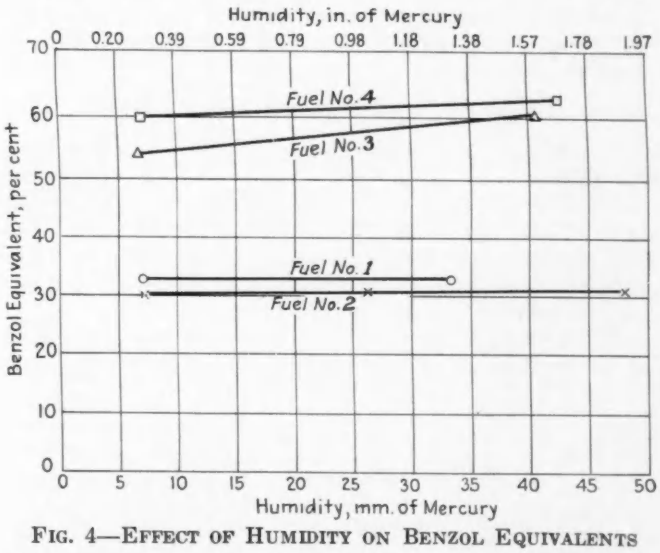


FIG. 4—EFFECT OF HUMIDITY ON BENZOL EQUIVALENTS

These Curves Show the Results of a Series of Detonation Tests Made on Four Fuels at Low and at High Humidities

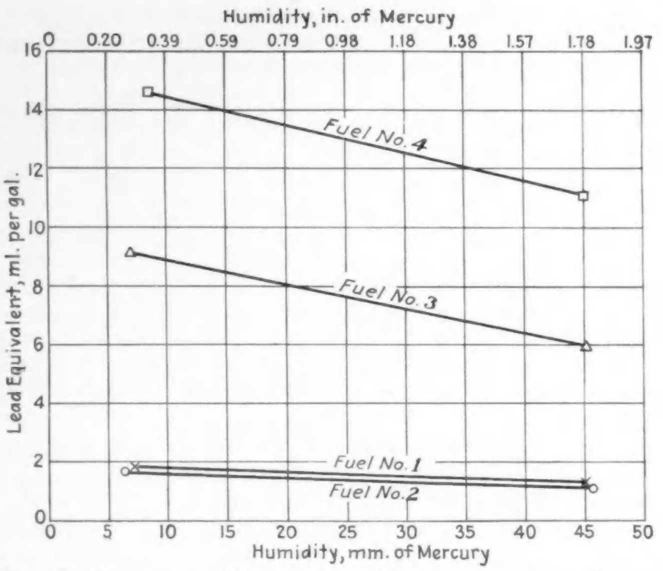


FIG. 5—EFFECT OF HUMIDITY ON TETRAETHYL-LEAD EQUIVALENTS

These Curves Show the Results of a Series of Detonation Tests Made on Four Fuels at Low and at High Humidities

tion between the lead equivalents and the humidity. Unlike the results obtained with benzol, these results show that the change in lead equivalent with change in humidity is definitely greater than experimental error. However, the change in humidity during any one working day is rarely as great as 10 mm. (0.394 in.) of mercury; hence it would not ordinarily be necessary to include a correction for humidity when comparing results obtained on one day. If, however, results obtained on different days are to be compared, it is apparent that the errors introduced by changes in humidity may be important.

The range of humidity here used is about equal to the maximum annual range for most stations north of the City of Washington, hence the deviations shown in Table 3 may be taken as representative of the limits of variation of benzol and lead equivalents of these types of fuel, when rated by this method. During the winter, the monthly humidity ranges in such stations is probably less than 10 mm. (0.394 in.) of mercury; its effect on the benzol and lead equivalents can therefore be neglected.

Effect of Humidity on Absolute Knock

By adding separately tetraethyl lead and benzol to the Pennsylvania-base fuel when operating at a humidity of about 7 mm. (0.276 in.) of mercury, the detonation of the pure-base fuel at the same throttle opening at about 45 mm. (1.77 in.) of mercury humidity was matched. Test conditions and results are given in Table 5.

From these data, it is possible to estimate the order of magnitude of the error introduced by variation in humidity in the interval between measuring or adjusting for a given intensity of detonation of the test fuel and that of the reference fuel.

TABLE 6—EFFECT OF AIR TEMPERATURE ON RELATIVE DETONATION

	Intake Air: Temperature,		Intake Air: Humidity,		Intake Air: Barometer,		Equivalent Hot		Equivalent Cold	
Fuel No.	Deg. Cent.	Deg. Fahr.	Mm. of Mercury	In. of Mercury	Mm. of Mercury	In. of Mercury	Benzol in Fuel A-1, Per Cent	Tetraethyl Lead in Fuel A-1, Ml. per Gal.	Benzol in Fuel A-1, Per Cent	Tetraethyl Lead in Fuel A-1, Ml. per Gal.
1	53.3	127.9	12.3	0.484	770	30.315	34.0			
	23.3	73.9	11.4	0.449	756	29.764			36.8	
	53.4	128.1	11.2	0.441	772	30.394		1.51		
	22.4	72.3	11.4	0.449	756	29.764				1.78
2	51.0	123.8	11.8	0.465	770	30.315	34.6			
	21.0	69.8	11.4	0.449	759	29.882			42.4	
	52.2	125.9	10.5	0.413	770	30.315		1.66		
	21.6	70.9	11.45	0.451	756	29.764				2.02
3	56.7	137.7	9.0	0.354	765	30.118	58.7			
	22.2	72.0	11.4	0.449	756	29.764			55.2	
	52.4	126.3	10.05	0.396	772	30.394		9.75		
	24.1	75.4	11.75	0.463	756	29.764				7.8
4	54.2	129.6	7.2	0.283	765	30.118	64.9			
	25.2	77.4	8.2	0.323	758	29.842			63.5	
	54.0	129.2	8.0	0.315	760	29.921		14.3		
	24.8	76.6	8.3	0.327	756	29.764				14.5

Under the best conditions and when working by ear, an evaluation or adjustment for a given intensity of the detonation can be obtained in about 1 min., since this interval is required for equilibrium of detonation to be attained. With the bouncing-pin method, another minute is required to obtain a reading. In the period during which atmospheric humidity has been regularly recorded in the Automotive Laboratory of the Bureau of Standards, the greatest observed rate of variation of humidity was 0.4 mm. (0.0157 in.) of mercury per min., this occurring immediately before a summer thunderstorm. In the 2 min. intervening between evaluations of the detonation of the test and reference fuels, it is therefore possible for the humidity to increase by 1 mm. (0.0394 in.) of mercury. This would cause an error in detonation rating of 1.5 per cent of benzol, or of 0.05 ml. of tetraethyl lead per gal. Hence even in this extreme case, the additional error introduced by humidity variation during tests is of the order of magnitude of the experimental error. If, however, a much greater time elapses between two tests intended to be comparative, a very appreciable error may be introduced by variation of humidity under unusual circumstances.

The foregoing discussion, while based on the assumption of a single matching of test and reference fuel, applies equally to the case of alternate runs on test and reference fuels, unless the first and last runs are made on the same fuel, and if the rate of variation of humidity is constant.

Purely as a matter of interest, tests were made to determine whether the decrease in absolute detonation with increase in humidity was due solely to lower

TABLE 5—EFFECT OF HUMIDITY ON ABSOLUTE KNOCK

Intake Air: Barometer		Intake Air: Increase of Humidity		Intake Air: Temperature		Corresponding Equivalents	
Mm. of Mercury	In. of Mercury	Mm. of Mercury	In. of Mercury	Deg. Cent.	Deg. Fahr.	Benzol, Per Cent	Lead, Ml. per Gal.
764.8	30.11	33.5	1.32	40.0	104.00	48.6	...
769.0	30.28	39.7	1.56	39.9	103.82	...	2.13

power, or whether the water vapor exerted an antiknock effect in addition to its diluent action. Tests were run at 44 and 10 mm. (1.73 and 0.394 in.) of mercury humidity, throttling the engine at the lower humidity to give detonation equal, by bouncing-pin, to that obtained at the higher humidity. At the higher humidity the throttle could be opened to give an increase in total air-flow of 13.7 per cent, and an increase in power, and hence in dry air-flow,[6] of 8.5 per cent, at equal detonation. The increase in humidity, expressed in terms of total pressure, was 4.5 per cent. In a subsequent test, these results were confirmed at a different compression-ratio, the increase in humidity being from 9 to 47 mm. (0.354 to 1.85 in.) of mercury or 5.0 per cent of the total pressure, and the permissible increase in power for equal detonation being 11.7 per cent. The results are shown diagrammatically in Fig. 6.

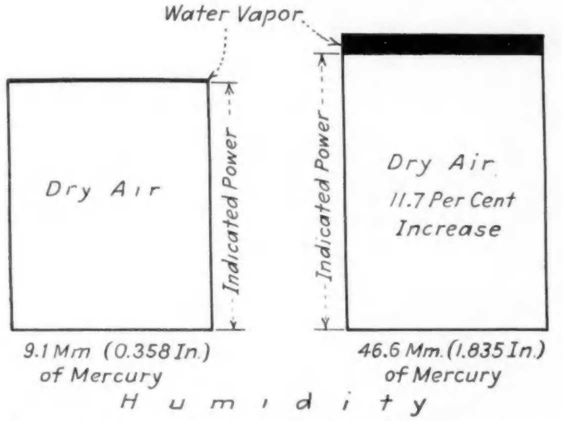


FIG. 6—POWER FOR EQUAL DETONATION AT LOW AND AT HIGH HUMIDITY

The Diagrams for Low and High Humidities Show That an Increase in Humidity of 1 Per Cent of the Total Pressure Allows a 2-Per Cent Increase in Power, Equivalent to a 3-Per Cent Increase in Charge Volume, for Equal Detonation

Effect of Air Temperature on Relative Detonation

In determining the effect of air temperature on relative detonation, the lead and benzol equivalents of each of the four fuels were found at each of two temperatures differing by about 30 deg. cent. (54 deg. fahr.). All conditions except temperature were maintained as nearly constant as practicable throughout this series of tests. The results of these tests are illustrated in Fig. 7 and are tabulated, together with relevant data, in Table 6.

Fuels No. 1 and No. 2 show a decrease in both benzol and lead equivalents at the higher temperature. Fuel No. 3 shows a slight increase in benzol, and a marked increase in lead, equivalents at the higher temperature, while Fuel No. 4 shows no significant change in either the benzol or the lead equivalent. The greatest change in benzol equivalent occurs with Fuel No. 2, and is about 1/4 per cent per deg. cent. (0.14 per cent per deg. fahr.). Fuel No. 3 shows the largest variation in tetraethyl-lead equivalent, this being about 0.07 ml. per gal. per deg. cent. (0.039 ml. per gal. per deg. fahr.).

[6] See S.A.E. JOURNAL, September, 1929, p. 277.

While it is always dangerous to generalize from few data, the results obtained certainly indicate that care should be taken to prevent drafts of colder or warmer air from entering the carbureter during tests. It is also unwise to attempt ratings at a time when the room temperature is being increased or decreased materially. Both of the above statements, naturally, assume absence of precise temperature regulation of carbureter air.

Effect of Air Temperature on Absolute Detonation

The question of the effect of air temperature on absolute detonation was approached from two viewpoints: first, the variation in intensity of detonation at a fixed throttle-setting when temperature is altered, and second, the quantity of benzol required to suppress detonation at equal power-output at a higher temperature. The first of these two aspects will furnish information as to the effect of small accidental variations in temperature while rating a fuel; the second indicates the effect of air temperature as in the case of an automobile when the power demand is constant.

In making these tests, the engine was operated detonating with the Pennsylvania-base fuel at 20 deg. cent. (68 deg. fahr.) and five readings of gas evolution were taken on the bouncing-pin apparatus. Without altering the throttle, the air was then heated to over 50 deg. cent. (122 deg. fahr.) and another set

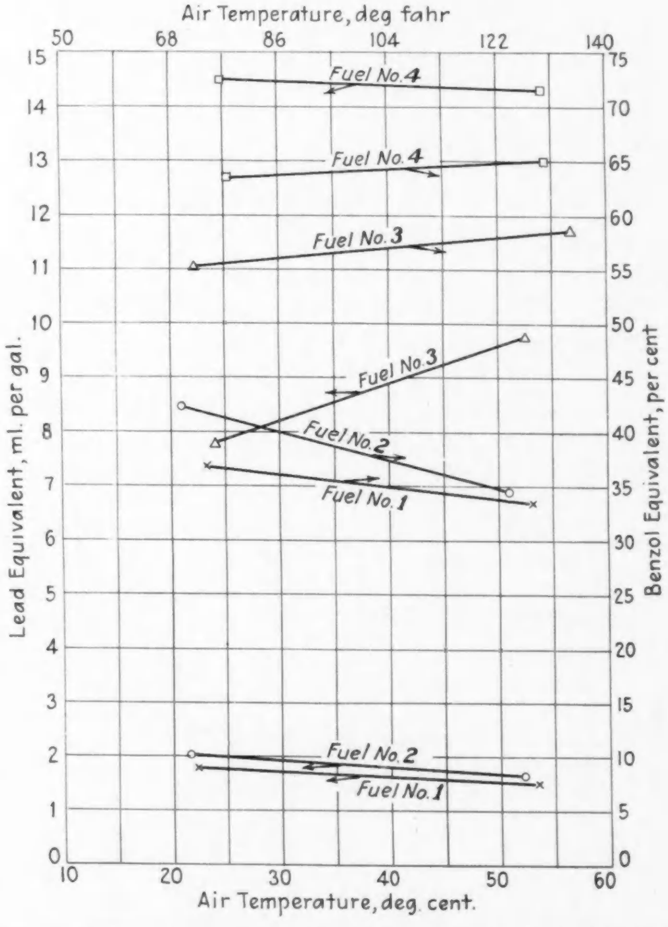


FIG. 7—EFFECT OF AIR TEMPERATURE ON BENZOL AND TETRAETHYL-LEAD EQUIVALENTS

These Curves Show the Results of a Series of Detonation Tests Made on Four Fuels at Low and at High Intake-Air Temperatures

TABLE 7—EFFECT OF AIR TEMPERATURE ON ABSOLUTE DETONATION

Throttle Opening, Deg.	Intake Air Temperature, Deg. Cent.	Intake Air Temperature, Deg. Fahr.	Intake Air Humidity, Mm. of Mercury	Intake Air Humidity, In. of Mercury	Intake Air Barometer, Mm. of Mercury	Intake Air Barometer, In. of Mercury	Maximum Power, I. Hp.	Benzol for Equal Detonation, Per Cent
12.9	20.1	68.2	9.8	0.386	760	29.921	1.98	0
12.9	52.3	126.1	10.9	0.429	758	29.842	1.89	0
13.9	55.2	131.4	11.0	0.433	758	29.842	1.98	42.5

of five readings of gas evolution was taken. Since the averages of the two sets of readings were equal within 1 per cent, it is considered that, with this fuel, and at the fixed throttle-setting used, air temperature had no effect on intensity of detonation.

Previous tests with a fuel which did not detonate had established the power output with cold air at the throttle setting 12.9 deg.; with the same fuel, using air at about 50 deg. cent. (122 deg. fahr.) the throttle was now adjusted to 13.9 deg. to give power equal to that obtained at the lower temperature. Tests were then made to determine the amount of benzol which, when added to the Pennsylvania-base fuel, would give detonation at this higher throttle just equal to that obtained with the pure Pennsylvania-base fuel at the original lower throttle and temperature. This was found to be 42.5 per cent benzol. Results are tabulated in Table 7.

Since with this reference fuel and at fixed throttle no variation in intensity of knock was noted with change in temperature, it is to be presumed that the change in benzol and lead equivalents in the case of Fuels Nos. 1, 2, 3 and 4 is due either to a change of the antiknock values of these fuels, or in the knock-suppressing values of the benzol and tetraethyl lead.

In passing, it may be noted that the observed increase of power with decrease in temperature was 4.7 per cent, as compared with the computed value of 5.3 per cent, based on the inverse square-root formula for correcting power for air temperature.

Effect of Temperature on Relative Detonation of Fuels of Widely Different Volatilities

To determine whether two fuels having radically different types of volatility curves would show different changes in antiknock value under different degrees of

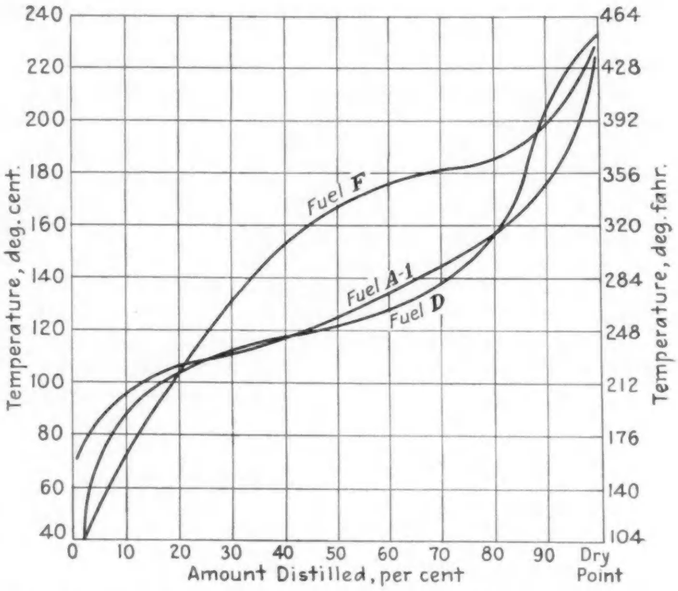


FIG. 8—AMERICAN SOCIETY FOR TESTING MATERIALS DISTILLATION CURVES OF FUELS USED IN DETONATION TESTS MADE TO STUDY THE EFFECT OF VAPORIZATION ON ANTIKNOCK VALUE

The Fuels *D* and *F* Were Selected for Wide Difference in Type of Distillation; Fuel *A*-1 Is the Reference Fuel

vaporization, two of the Cooperative Fuel Research acceleration-test fuels, *D* and *F* were compared with the Pennsylvania-base fuel, matching by adding separately tetraethyl lead and benzol to the reference fuel, and with normal heptane-iso-octane blends. The distillation curves of *D*, *F* and the Pennsylvania Fuel, labeled A-1, are shown in Fig. 8.

Tests were made at low intake-air temperature with the manifold jacket at 10 deg. cent. (50 deg. fahr.) and again with intake air over 50 deg. cent. (122 deg. fahr.) and the manifold steam jacketed. Fig. 9 illustrates the results, which are tabulated with relevant data in Table 8.

That a real change in antiknock value of Fuels *D* and *F* occurs between the two sets of conditions is obvious from Fig. 9, since all lines slope upward to the right. The proportionate increase in antiknock value with increase in vaporization is also greater in

TABLE 8—EFFECT OF TEMPERATURE ON RELATIVE DETONATION OF FUELS OF WIDELY DIFFERENT VOLATILITIES

Fuel	Intake Air Temperature, Deg. Cent.	Intake Air Temperature, Deg. Fahr.	Intake Air Humidity, Mm. of Mercury	Intake Air Humidity, In. of Mercury	Intake Air Barometer, Mm. of Mercury	Intake Air Barometer, In. of Mercury	Intake-Manifold Jacket Temperatures, Deg. Cent.	Intake-Manifold Jacket Temperatures, Deg. Fahr.	Equivalent Hot: Benzol in Fuel *A*-1, Per Cent	Equivalent Hot: Tetraethyl Lead in Fuel *A*-1, Ml. per Gal.	Equivalent Hot: Iso-Octane in Normal Heptane, Per Cent	Equivalent Cold: Benzol in Fuel *A*-1, Per Cent	Equivalent Cold: Tetraethyl Lead in Fuel *A*-1, Ml. per Gal.	Equivalent Cold: Iso-Octane in Normal Heptane, Per Cent
D	50.0	122.0	9.2	0.362	763	30.039	100	212	36.5					
	22.8	73.0	9.2	0.362	762	30.000	10	50				27.8		
	55.1	131.2	10.8	0.425	758	29.842	100	212		1.26				
	20.4	68.7	10.4	0.409	759	29.882	10	50					1.15	
	54.9	140.8	10.8	0.425	758	29.842	100	212			58.3			
	20.1	68.2	10.6	0.417	759	29.882	10	50						57.4
F	50.0	122.0	9.2	0.362	763	30.039	100	212	20.8					
	21.5	70.7	8.9	0.350	762	30.000	10	50				9.1		
	49.5	121.1	10.0	0.394	752	29.606	100	212		0.65				
	17.5	63.5	5.4	0.213	750	29.528	10	50					0.57	
	55.1	131.2	10.8	0.425	758	29.842	100	212			49.6			
	20.4	68.7	10.6	0.417	759	29.882	10	50						47.2

every case with Fuel *F* than with Fuel *D*. Furthermore, as Fuels *D* and *A*-1 have very similar distillation curves, it appears that temperature may have decidedly different effects on the detonation of fuels of the same volatility. Lastly, on comparing the results obtained against heptane-octane—which should at least be affected by changes in vaporization, being pure substances of nearly equal volatility—with those when using benzol or lead, it appears that while the knock-suppressing value of the lead is affected little, if any, by temperature over the range studied, that of benzol is decidedly greater at lower temperatures.

Effect of Barometric Pressure on Relative Detonation

The lead and benzol equivalents of each of the four test-fuels was determined at each of two barometric pressures, the air temperature, humidity and other test-conditions being maintained essentially constant.

The results are illustrated in Figs. 10 and 11, and are tabulated, together with other relevant data, in Table 9.

As in the case of the relative-detonation tests at different humidities, while there is a consistent tendency to higher benzol and lead equivalents at higher pressures, the actual differences are but little larger than the possible experimental errors, especially since comparative tests could not be made on the same day. However, the consistency of the results on the different fuels and between the lead and benzol equivalents seems to indicate a real effect. Perhaps the best conclusion which can be drawn from these meager data is that lead or benzol equivalents obtained at baro-

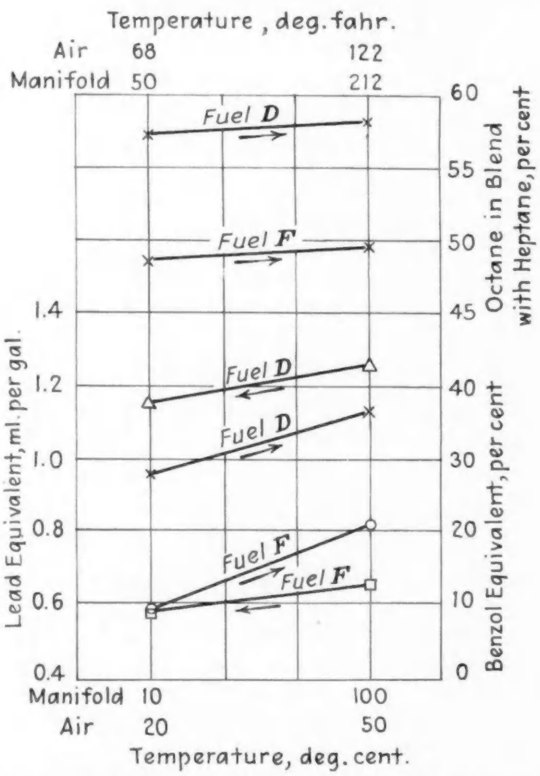


Fig. 9—Effect of Vaporization on Relative Detonation

Fuels *D* and *F* Were Rated, at Conditions Conducive to Wide Differences in Vaporization, against Both Benzol and Tetraethyl Lead in *A*-1, and against Heptane-Iso-Octane

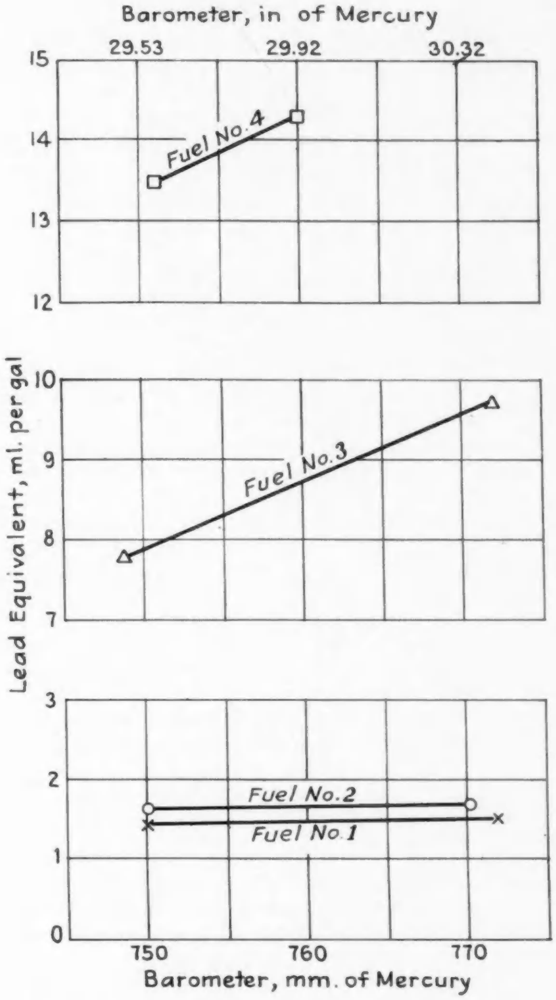


Fig. 10—Effect of Barometric Pressure on Benzol Equivalents

These Curves Show the Results of a Series of Detonation Tests Made on Four Fuels at Low and at High Barometric Pressures

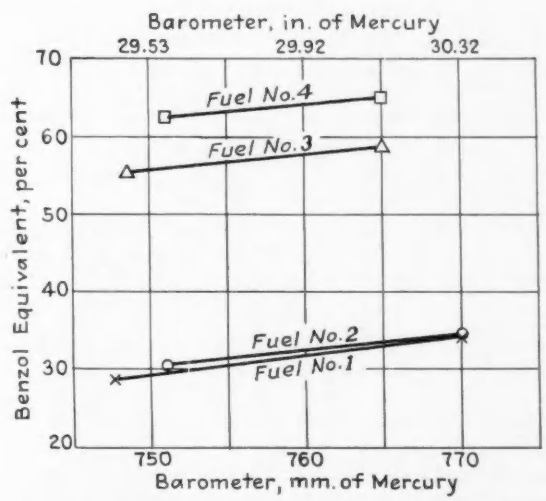


Fig. 11—Effect of Barometric Pressure on Tetraethyl Lead Equivalents

These Curves Show the Results of a Series of Detonation Tests Made on Four Fuels at Low and at High Barometric Pressures

metric pressures differing by more than 2 cm. (0.787 in.) of mercury should be compared only with mental reservations.

TABLE 9—EFFECT OF BAROMETRIC PRESSURE ON LEAD AND BONZOL EQUIVALENTS

	Intake Air Humidity,		Intake Air Temperature,		Barometer,		Equivalents	
Fuel No.	Mm. of Mercury	In. of Mercury	Deg. Cent.	Deg. Fahr.	Mm. of Mercury	In. of Mercury	Benzol, Per Cent	Tetraethyl Lead, Ml. per Gal.
1	12.3	0.484	53.3	127.9	770	30.315	34.0	...
	11.4	0.449	50.4	122.7	748	29.449	28.5	...
	11.2	0.441	53.4	128.1	772	30.394	...	1.51
	10.7	0.421	51.6	124.9	750	29.528	...	1.45
2	11.8	0.465	51.0	123.8	770	30.315	34.6	...
	10.5	0.413	50.5	122.9	751	29.567	30.5	...
	10.5	0.413	52.2	126.0	770	30.315	...	1.66
	10.7	0.421	50.9	123.6	750	29.528	...	1.61
3	9.0	0.354	56.7	134.1	765	30.118	58.7	...
	11.8	0.465	50.8	123.4	748	29.449	55.2	...
	10.5	0.413	52.4	126.3	772	30.394	...	9.75
	11.6	0.457	50.0	122.0	749	29.488	...	7.8
4	7.2	0.283	54.2	129.6	765	30.118	64.9	...
	10.4	0.409	50.9	123.6	751	29.567	62.5	...
	8.0	0.315	54.0	129.2	760	29.921	...	14.3
	10.3	0.406	50.1	122.2	751	29.567	...	13.45

Conclusions

From the results of this investigation, which cannot as yet be considered as either complete or conclusive, the following are indicated as being reasonably certain:

(1) The effect of day-to-day variations in atmospheric humidity, such as occur in winter, on the relative detonation of normal fuels when rated against benzol, is negligible. The effect of summer variations in humidity is small.

(2) For the fuel tested, the effectiveness of tetraethyl lead increases materially with the increase in humidity. Ratings against tetraethyl lead may safely be compared if made on the same day in summer, or if made during the same month in winter. Otherwise it seems probable that control of, or correction for, humidity will be necessary.

(3) The effect of variations in humidity occurring between successive detonation determinations is negligible unless made under abnormal conditions and with an interval of more than 2 min. between tests.

(4) Both volatility of, and hydrocarbon series present in, fuels affect the rate of variation of detonation with change in air temperature.

In addition the following deductions are indicated as being probable:

(1) In rating normal fuels, air temperature should be maintained reasonably constant, for example, in a range not exceeding 5 deg. cent. (9 deg. fahr.).

(2) In general, with normal fuels, the effect of variation in air temperature on absolute detonation is largely compensated by the concomitant variation in charge weight.

(3) The change in effectiveness of tetraethyl lead as a knock suppressor when used in Pennsylvania-base gasoline in knock rating at varying temperatures is less than that of benzol.

(4) Comparison of lead or benzol equivalents may be subject to error if determinations were made under barometric pressures differing by more than 2 cm. (0.787 in.).

THE DISCUSSION

ROBERT E. WILSON[7]:—We have, without question, made considerable progress in testing antiknock fuels in the last two years. I think that the Bureau is putting the finishing touches now on what will be a satisfactory and reproducible method that should come into general use. This type of detail work, investigating the different factors, is necessary as a basis for standardizing such tests.

You will note that practically everyone has come to the proposition of matching two fuels. The old idea that you could measure antiknock fuels at different times and rate fuels in that way on an absolute basis has practically disappeared. So many factors in the condition of the engine and the atmosphere and other factors can change that only a match against some standard fuel, made almost simultaneously, can be relied upon to give an accurate measure of the detonating properties of the unknown fuel. Even such matching is, as these tests point out, subject to certain errors because two fuels that match under one set of conditions may not match under another.

The statement was made that in comparing fuels they should be compared at temperatures giving about the same degree of vaporization. Wording the statement in that way seems to assume that it is the degree of vaporization which determines the differences of antiknock occurring between those tests, which does not seem to me to be generally true. In other words, I believe that two fuels at temperatures at which they were both completely vaporized would show variation in comparative antiknock rating if the temperatures were not the same. The important thing, I think, is to compare the fuels at the same temperature.

Unquestionably we must have different standard conditions for testing fuels that are to be used in water-cooled engines and those to be used at the higher temperatures generally prevailing on air-cooled or glycol-cooled engines. Without any question benzol and hydrocarbon antiknocks in general lose their effectiveness more rapidly with increasing temperature than does tetraethyl lead.

In connection with the last chart that was shown giving the variation with different atmospheric pressures plotted against the quantity of lead required, I desire to point out that, while the milliliters of lead required sounds like a fairly satisfactory scale with which to plot such variations, actually those who work with tetraethyl lead realize that this scale is a fictitious one in that the first milliliter of lead has a great effect and the variation between 7 and 8 ml. is really a very small variation, comparatively.

We have made certain estimates on the relative efficiency of the first, second, third and fourth milliliters of tetraethyl lead in its knock-suppressing effect, and

[7] M.S.A.E.—Assistant to vice-president in charge of manufacturing, Standard Oil Co. of Indiana, Whiting, Ind.

while those comparisons involve certain assumptions they indicate, and I believe correctly, that the efficiency of the eighth milliliter of tetraethyl lead is less than 20 per cent as effective as the first milliliter of tetraethyl lead. Therefore, that variation is not nearly as great as would appear from that scale.

D. B. BROOKS:—I am very glad that Mr. Wilson has called attention to that point which should have been mentioned in the paper. I would have made a rough guess that the effect of the tenth milliliter was equal to about 1/10 of the first.

MR. WILSON:—I think that is about right.

MR. BROOKS:—The statement about vaporization was not made sufficiently clear. I did not mean to say that two fuels should be compared at the same degree of vaporization but that a test fuel should be rated at conditions such that its vaporization shall be approximately the same as it will be in service. If you intend putting it into a water-cooled engine, test it under conditions giving somewhere near the vaporization that you will have in water-cooled engines. The same holds true for the air-cooled engines.

MR. WILSON:—Does not that assume, in the way you put it, that the degree of vaporization is the important factor in the knock, whereas it may be a temperature effect? Suppose I am working with engine conditions in which 100 per cent fuel vaporization is obtained. That does not mean that any other temperature cannot be used, but that the temperature must be the same during the tests whether it gives the same or a different degree of fuel vaporization.

MR. BROOKS:—Yes.

Test Conditions Should Be Identical

CHAIRMAN W. S. JAMES[9]:—In connection with this kind of testing where the results are obtained from direct comparisons between the test fuel and the standard fuel, or a fuel with benzol or tetraethyl lead added, do conditions of the engine itself, such as leaking valves or carbon in the cylinder, change the relative relation between a test fuel and the standard of comparison? We know that it changes the absolute value but we do not know whether or not it changes the relative value.

MR. BROOKS:—That is listed in the file of unfinished business at the present time.

MR. WILSON:—I think we can say very definitely that anything which markedly affects the temperature conditions of the inside of the engine as a whole, or any part thereof, will show differences between what we can call hydrocarbon antiknocks, such as benzol, and tetraethyl lead. Two fuels that match under one set of engine conditions may not exactly match under another set if they involve a change in the temperature of the parts inside the engine.

CHAIRMAN JAMES:—Would it be necessary, in testing an engine in the City of Washington and another in Seattle, to be sure that they were in relatively the same mechanical condition?

MR. WILSON:—Yes, the cooling-water temperature should be the same and about the only way we can make carbon constant is to keep it negligible.

CHAIRMAN JAMES:—The basis of the work, however, would be a comparison between the same fuel as used in both engines. Am I correct that the only question then would be on the rate of variation of the antiknock value of that fuel due to the difference in the condition of the two engines?

MR. WILSON:—We know that to be sure of check results the condition of the engines must be substantially the same.

CHAIRMAN JAMES:—How much that condition can vary is not certain. For example, on one day a car will not climb a hill with a given load and the day before it did. We clean out the carbon, which is probably less than 1/64 in. thick and maybe is 1/32 in.; and after that the car will climb the hill. It seems absurd but it has happened. Do such conditions change the rating of the two fuels? In some cases the apparent difference is very much greater than what would be expected.

MR. WILSON:—Those conditions unquestionably will change the rating of the fuels.

H. K. CUMMINGS[9]:—In trying to survey this field, which is full of variables, we tackle these things, one at a time or in groups. The method of investigating the effect of atmospheric conditions is to operate with all other conditions identical to get these facts uncomplicated by other things. Of the various possible ways of rating fuels that may come out of the cooperative work now being done, some may be much more sensitive to changes in engine conditions than others. A separate investigation, with atmospheric conditions and all other factors except engine condition controlled, is planned to ascertain whether certain of the methods are influenced more than others by changes in engine condition. By taking these things up a few at a time we hope to collect information as to whether under specified testing-conditions, none of which are necessarily the ultimate, particular kinds of variable are important or not. We must take into account equally, in our final answer, the effect of atmospheric conditions, the effect of engine conditions and the effect of numerous other variables on the choice of test conditions. Whether entirely different tests and ratings for fuels to be used in motor-car engines and water-cooled aircraft and air-cooled aircraft engines will be necessary or whether the results of one sort of test can be interpreted in their application to the other conditions or not is an open question in my mind at present.

CHAIRMAN JAMES:—I do not mean to imply any criticism of the method that has been followed, but the question about engine conditions arose in my mind because, unfortunately, some of us have had fairly peculiar experiences with engines at times when they did not do what they should have done.

Relation between Mixture-Ratios and Knocking Tendencies

O. C. BERRY[10]:—I noticed that Mr. Brooks in his graphs is plotting the ratio of air to fuel against the detonating tendencies of his fuel. I would like to ask if he has discovered a definite relationship between mixture-ratios and knocking tendencies?

MR. BROOKS:—If knock intensities are plotted against mixture-ratios, the curve is of the parabolic type and shows, therefore, a fairly slight variation in the in-

[8] M.S.A.E.—Research engineer, Studebaker Corp., South Bend, Ind.
[9] S.M.S.A.E.—Chief of the automotive powerplant section, Bureau of Standards, City of Washington.
[10] M.S.A.E.—Motor engineer, Buick Motor Co., Flint, Mich.

tensity of detonation, very close to the region of maximum intensity, but a decided change as we go farther; that is, the farther we get from the maximum the faster the change. Hence there is a small region around maximum intensity in which we can safely work. If we get far off that region, as we may well do by using the setting for maximum power instead of maximum knock, then we will get into difficulty. We have had some trouble ourselves in that way, not hitting exactly the correct carbureter setting the first time. For example, if the test fuel is right on the peak and the reference fuel is a little way off, then much less benzol or lead is needed than if both of them were at the peak. One time we may hit one on the peak and not the other and at another time it might be just the reverse.

MR. BERRY:—Apparently I did not make myself clear. I wanted to get the relationship between the mixture-ratio for maximum power and for maximum detonation.

MR. BROOKS:—We have not thoroughly investigated that. Some evidence that the two are not at all times coincident has been found. In one test, which we made, we found the setting for maximum intensity of detonation, for maximum power and for maximum cylinder-pressures all coincided, I think, within 1 per cent, on one fuel. Considerable evidence seems to indicate that in some types of fuel the maximum knock occurs with a leaner mixture than that for maximum power. The method of setting by maximum power is at least unsafe.

CLIFFORD M. LARSON[11]:—We have found, with our make of high-compression gasoline, at Houston and our control laboratory at East Chicago, that we can get an appreciable difference in temperatures and humidity between the two places. We have come to the conclusion that, unless we have a Bureau of Standards set-up with Bureau of Standards operators, getting check results on the same sample is difficult.

GEORGE G. BROWN[12]:—Regarding the effect of engine conditions on the knock rating, perhaps a brief report of our experience may be in order. We make our knock-rating tests by taking the compression-ratios that give first audible detonation and those that develop maximum power with spark, air-fuel ratio and other conditions constant.

We have found that with undoped fuels, where the knock rating is due to composition of hydrocarbons that we have practically the same benzol-value by these two methods of testing. However, when we run into highly volatile paraffin hydrocarbons, such as natural gasoline, we find a noticeable difference in the benzol values as determined by first audible detonation and by the compression-ratio giving maximum power.

If we repeat these tests carefully we find that the maximum-power point that first comes in as soon as the compression-ratio is increased checks very closely the benzol value determined by audible knock. But, if we maintain the engine operating with a high knocking-intensity at maximum power with constant spark-setting, the highly volatile paraffin fuel shows a much higher benzol-value when tested on the basis of compression ratio for maximum power than when tested on the compression ratio for first audible knock. We know that the inside of the combustion-chamber operates at a higher temperature when we are operating the engine continuously with high knock-intensity than when operating at a lower knock-intensity at just audible detonation. This would seem to indicate that if the knock rating or the antiknock value of the fuel is due to the composition of the hydrocarbons more consistent results would be obtained if we are matching that fuel with a similar blend of hydrocarbons such as heptane and benzene or iso-octane. Perhaps this does not answer the question that was raised but I think it at least indicates that although changes in temperature may show less effect on blends of Pennsylvania gasoline and tetraethyl lead, we ought at least to keep our minds open on the question of using hydrocarbon blends, because the knocking qualities of such blends may be affected by temperature changes in about the same manner as the fuel being tested. As long as we are testing fuels, using a standard that has about the same characteristics as the fuels being tested has some advantage.

Regarding the question raised by Mr. Berry, we have found in most cases that the maximum intensity of knock comes at about a 13 to 1 air-fuel ratio, while the maximum power will be developed at 12.3 or 12.5 We agree with the statement made by Mr. Brooks that the point of maximum knock is frequently at a slightly leaner mixture than the point of maximum power.

ALBERT J. BLACKWOOD[13]:—Our experience on knock rating may be interesting inasmuch as we have nine laboratories scattered throughout the Country all the way from Calgary, Canada, to Baton Rouge, La., and naturally climatic conditions vary widely from one location to another. We have periodically been sending samples to each one of those laboratories for knock rating and we have yet to receive results that differ by more than + 2 per cent benzol in rating them.

Of course, for routine work we cannot conveniently control all the factors influencing the detonation, due to the large number of samples handled. We run anywhere from 30 to 50 per day. We attribute the closeness of these data to the fact that all of our laboratories have identical equipment and we have had a man go out to each laboratory and personally instruct the personnel on exactly how to conduct the tests and the exact technique that is to be followed. This technique even incorporates the kind of lubricating oil to be used.

In addition to that, we have two reference fuels to cover the range of normal gasolines and we add lead to those reference fuels, never in excess of 2 cc. per gal. In other words, we do not get into the range of the lead sensitivity where large quantities of lead are necessary to produce small changes in knock tendency.

In Mr. Brooks' paper he recommends that the fuels should be tested in the engine under conditions that give about the same evaporation in the test engine that the fuels are to have in operation on the car. For the refiner that is rather difficult. For example, our experimental cracking plant will send us a sample that represents the gasoline coming over between 300 and 350 deg. fahr. and ask for the knock rating. This is one of our problems that is very difficult to solve

[11] M.S.A.E.—Supervising engineer, Sinclair Refining Co., New York City.

[12] M.S.A.E.—Professor of chemical engineering, University of Michigan, Ann Arbor, Mich.

[13] Jun. S.A.E.—Assistant to the director of the fuel and lubrication research section, Standard Oil Development Co., Elizabeth, N. J.

with any set of engine conditions that will produce informative results.

Spark-Plugs and Detonation

A. J. SCAIFE[14]:—How much influence do the different makes of spark-plug have on detonation? We talk about keeping the spark exactly at the same point. I wonder if that has any effect?

In one case a passenger car had a high-compression head, with which we had to use a high-test fuel. By putting a straight-run gasoline into that same engine and running it one or two blocks, the detonation was excessive. By simply putting in another set of spark-plugs with that same fuel, the detonation disappeared and when the spark-advance was increased from 45 to 60 deg. we still did not get any detonation.

JOHN O. EISINGER[15]:—We made some tests on a car when using different types of spark-plug and had some trouble with detonation at high car-speeds. We bought a considerable number of different types of plug that the Champion people made and I know that we were able to stop the detonation at high car-speeds by changing the type of spark-plug.

NEIL MACCOULL[16]:—We have some data that might shed light on this matter. On our test engine we tried a series of A.C. spark-plugs, running from the lowest to the highest temperatures. We found no difference in the knock characteristics with any of these plugs on this test engine, which of course runs at low speed. However, a very different condition may exist when the engine is running at such high speed that the spark-plug gets very hot.

CHAIRMAN JAMES:—Did you use a comparative method, Mr. MacCoull, running one fuel immediately preceding or following the other?

MR. MACCOULL:—Yes, and the knock was no different either by the absolute method, as Mr. Brooks calls it, or by the comparative method.

OTTO C. ROHDE[17]:—In tests of this kind we make too little distinction between detonation and what usually comes along with it in running hot types of plug, incipient preignition, that is, not audible preignition but an overheating, sufficient to cause a change in what is usually rated as detonation knock, the latter being the beginning of preignition. We can tell that very clearly when we use a plug hot enough to cause actual preignition and note the change as we pass from detonation with high spark-plug temperature into actual preignition that stops the engine.

MR. WILSON:—Is not that detonation even though it may be caused by incipient preignition?

MR. RHODE:—The two are not differentiated as much as they should be.

SAMUEL P. MARLEY[18]:—In this discussion of spark-plugs I am wondering how much trouble may be caused by leakage of current over the porcelain of one plug more than another? We have discussed plugs here considerably but nothing has been said about the effect of spark and voltage or current on detonation. In our equipment we have a rheostat in the primary circuit of the ignition system to make it easily handled under variable conditions. We can produce very heavy detonation in that engine or bring it down to where nothing is heard at all simply by a small adjustment of the primary voltage which means that spark and voltage have considerable to do with the volume of detonation.

I might add that we have observed the same effect on detonation when using a road car as was found in the laboratory engine. By varying the primary voltage and amperage in the ignition circuit the detonating characteristics varied. The fuel knock could be entirely eliminated or increased depending on the primary voltage.

This variation in voltage or current necessary to affect detonation will, of course, be different when the engine is hot as compared with when it is cold. The pressure in the cylinder or throttle setting is another factor that is very closely related to sparking voltage. So many variable factors affect the voltage which in turn affects detonation, the latter being of much interest to us, that we have found a study of these variables necessary. The results of this investigation when completed may be of sufficient interest to warrant presentation in the near future.

MR. BROWN:—We can check directly the statement made by Mr. Marley, and even go a little farther. We can sometimes decrease detonation to a great extent by control of the secondary circuit without changing voltage. Whatever influence different spark-plugs may have on the igniting spark may be a rather important effect on the engine knock.

CHAIRMAN JAMES:—Was that a question of spark timing or spark intensity?

MR. BROWN:—Spark intensity and spark quality at the same timing.

CHAIRMAN JAMES:—With reference to Mr. Rohde's point, I have seen cases where we have preignition without audible detonation. I believe that is particularly true with benzol at very high compression where it will preignite before audible detonation takes place. I know that in many cases preignition and detonation are confused. We can get preignition without any audible detonation or any noticeable detonation. All of a sudden we are into preignition with its subsequent difficulties.

MR. WILSON:—That is perfectly true, but if we have an engine that is operating in the detonation range and on the verge of preignition due to a hot spark-plug or anything else, not only do we get a little preignition but we also get a very marked increase in knock intensity. It is caused, probably, by incipient preignition, but whatever the cause the result is to increase detonation.

CHAIRMAN JAMES:—That is probably true and makes the determination of whether a noise is preignition or detonation very difficult at times. I think that has caused considerable uncertainty a number of times.

MR. WILSON:—My pure guess, as far as any data are concerned on these statements regarding the effect of spark, is that when they are fully analyzed they will be found to tie in with that same phenomenon. Over a very wide range where the plugs are not very hot, the variation in current and the spark will not make any particular difference in detonation. But, if we approach the point of preignition, or where the

[14] M.S.A.E.—Consulting fuel engineer, White Motor Co., Cleveland

[15] M.S.A.E.—Research engineer, Standard Oil Co. of Indiana, Whiting, Ind.

[16] M.S.A.E.—Automotive engineer, Texas Co., New York City.

[17] M.S.A.E.—Chief engineer, Champion Spark Plug Co., Toledo.

[18] M.S.A.E.—Research engineer in petroleum technology, Mellon Institute of Industrial Research, Pittsburgh.

spark-plug electrodes are getting hot enough to have some influence on the detonation, whatever the mechanism may be, then the variation in the spark will have an effect.

CHAIRMAN JAMES:—You start a preignition and make the bonfire worse by firing it with a plug.

MR. WILSON:—You heat the plug hotter for one thing, and you change the plug temperatures.

MR. MARLEY:—I would like to differ explicitly with Mr. Wilson on that point insofar as I cannot feel that it is directly related to the spark and voltage, for the simple reason that we can sit there and play our little tune on that engine, on an engine that has just been started, and therefore we have cold electrodes. By simply varying our spark and voltage in the primary, which no doubt does the same thing in the secondary as Mr. Brown has pointed out, we can change our knock intensity. We can do that immediately after starting, or we can do it after we have run an hour and have everything warmed up. I think it is proportional to the spark and voltage, or should we say current.

MR. SCAIFE:—The only reason that I raised this question was that we were talking about having engines exactly the same. I wonder if we ought not to have similar ignitions, spark-plugs and everything that has to do with the engine entirely the same?

I will tell you the end of the incident. This job idled nicely at 2 m.p.h. It was run up to 89 m.p.h., by the speedometer, and it was dropped back to 2 m.p.h. without any bucking. Inasmuch as it smoothed down to 2 m.p.h. again after this burst of speed it rather exploded the theory that any preignition was due to the spark-plug.

MR. ROHDE:—In that connection, to know the comparative gap-settings of the two sets of plugs used would be interesting as that would have a direct bearing on the matter of idling down.

MR. SCAIFE:—I do not know; the change was made, but nothing else was changed. The spark-plugs were taken out and this other set was put in without anything else being changed. After two or three runs that way were made the advance was simply changed to give 15 deg. more. I do not know whether anything outside of that was done or not.

CHAIRMAN JAMES:—In connection with the point that Mr. Scaife raised as to the parts of the engine that are to be used in this work in detonation comparison, the plan is to use identical engines, carbureters, spark-plugs, valves and all the accessories. I think the point of intensity of spark voltage may be of some interest and probably will be taken care of in the tests later.

One question that has occurred to me is whether or not a definite relationship exists between the weight of charge per cycle and the antiknock value, that is, for a given engine does not the detonation follow the weight of charge actually entering the engine? Does that tie in with the change in temperature and in pressure?

MR. BROOKS:—In the temperature experiments at fixed throttle, the charge weight necessarily altered as the temperature was increased. We checked this change against the computed value obtained from the inverse square-root formula. The observed variation of charge weight as estimated by power was 4.7 per cent, and the computed was 5.3, which is within the experimental error of power measurement on this engine.

When the throttle was left fixed so that the weight of charge varied as the temperature was increased, no change in the intensity of detonation was noticed. When the charge was increased at the higher temperature by opening the throttle to give the power equal to that obtained at the lower temperature about 40 per cent of benzol was required to suppress the additional detonation; that is, to bring the detonation back to its original value.

MR. BLACKWOOD:—With regard to that last question, our test engines are about 7.5 to 1 compression-ratio and in checking a mixture of normal heptane and iso-octane in volumetric proportions of about 55 to 45, those proportions were exactly equal to the same proportions of heptane and benzene. In testing these bad knocking blends the throttle has to be fairly well closed.

When the throttle is opened for testing blends in proportions of about 30 per cent of heptane and 70 per cent of iso-octane, the difference between the iso-octane-heptane mixture and the benzene-heptane mixture amounts to approximately 15 to 20 per cent of benzol. In other words, where the charge weight is small, benzene and iso-octane have about the same antiknock tendency. When the throttle is open and the weight charged is much greater, then the benzene has a much greater antiknock value than the iso-octane. These data are influenced by large differences in the ratio of fresh charge to residual exhaust gas in the two cases.

MR. CUMMINGS:—That observation is in accord with the findings of Campbell, Lovell and Boyd.[19] The throttling is essentially equivalent to reduction of the compression-ratio, and at a low compression-ratio the two blends, as he mentions, are equal; at a higher ratio the superior effectiveness of benzene as a knock-suppressor becomes apparent.

MR. BROWN:—I think the last two speakers have missed a very important point. High blends of benzene and heptane have a very high knock-rating, while high percentages of iso-octane and heptane show relatively much lower knock-rating. In fact a blend of 85 per cent of benzene and 15 per cent of heptane is just as good as pure iso-octane, although up to 50 per cent of benzene or iso-octane in heptane, the two blends show the same knock rating. These characteristics may have nothing whatever to do with the density of the charge, simply that benzene has an extremely high antiknock value. In fact, I have never been able to make it knock at all with water temperature of 175 deg. fahr. with compression-ratios up to 15 to 1, while iso-octane will knock at a much lower compression-ratio.

[19] See S.A.E. JOURNAL, February, 1930, p. 163.

The Body Problem and Its Solution

By
E. C. GORDON ENGLAND[1]

Annual Meeting Paper

Illustrated with
Photographs and Drawings

THE WHOLE problem of the body is attributed by the author to the standard practice of attaching the body to the chassis and the hood dashboard by a series of bolts or set-screws and then attaching the hood, fenders and running-boards partly to the chassis and partly to the body.

In short, the chassis and the body are treated as if they were a unit, whereas, in fact, the chassis is a flexible unit and the conventional body is a relatively rigid unit. As a consequence of interaction of the two, the body is twisted and racked and develops squeaks and rattles. To prevent this condition, the builders have built bodies more substantial and as a consequence they have become much heavier, which has necessitated building heavier chassis. In turn, this increased weight of the vehicle has militated against quicker acceleration and quicker stopping.

The author lists eight requirements demanded of the body by the public and discusses each of these. He also divides body engineers and builders into three classes: those maintaining that, as the chassis is flexible, the body must be flexible; those who maintain that the body must be made so strong and rigid that it will make the chassis frame rigid; and those who seek a solution through the introduction of some form of insulation between the two components.

Examples of the flexible, the rigid and the insulated body are cited and the advantages and success of each type are conceded. The author then describes his own experiments, starting with the premise that all chassis are flexible and that, if the body could be completely insulated from the action of the chassis and the load, the major problems would be solved. How these ideas were embodied in a light, homogeneous, rigid structure that floats unstressed on the chassis and is completely and lastingly quiet is illustrated and described.

Many questions regarding details of construction are asked by discussers and answered by the author. Specific examples of large weight-saving are given and the questions of relative movement of the body and the passengers, exclusion of rain, connection between body and hood, mounting of the running-boards and so on are discussed. Several but not all of the discussers agree that the author is on the right track in seeking a solution of the body problem.

BODY mounting is defined, for the purpose of this paper, as including the attachment of the body, the hood, the fenders and the running-boards to the chassis structure.

In the past, the generally accepted method the world over of body mounting has been to attach the body to the chassis and to the hood dashboard by a series of bolts or set-screws; following upon this, the hood, the fenders and the running-boards are attached sometimes partly to the body and partly to the chassis, and with variations of small moment this may be described as standard procedure. In itself there is nothing very remarkable about this fact, but it is in the consequences of that act that the whole problem develops into a matter of great magnitude.

We must here consider the nature of resultant difficulties which arise from a seemingly simple set of circumstances, and to do this effectively we shall examine for a moment certain fundamental facts that I submit are of great importance.

The admitted object is to obtain an automobile which, regarded as a whole, is as silent, smooth and restful as it is possible to conceive and construct. To this end the chassis engineer has devoted great thought, and it is true to state that his efforts have been rewarded with a considerable measure of success. Such noise as still exists in the average modern chassis is soft and sometimes almost pleasing in its effect. This state of well-being is constantly being upset by intermittent noises developing in what is sweepingly regarded as the body. Again, in some cases, a periodicity almost unnoticeable in the chassis is unpleasant when magnified by that sound amplifier, the body.

The problem, briefly, is how to control this undesirable feature, described as body noises, which in the mind of the ultimate buyer is far more noticeable because it may be described as intermittent and therefore at once appreciable to the most uninformed person. This problem has confronted the automobile industry in all lands for many years, and it seems a surprising thing that no fundamental attack has been made upon the root cause of the trouble.

The Fundamental Cause of Trouble

The nature of the average chassis can be stated as that of an elastic and flexible body; and, as we know, an elastic body has movement to a greater or lesser degree within itself, governed by the amount of elasticity inherent in that body.

The average automobile body is by nature almost an inelastic structure, except in those directions in which the body designer would welcome an infinite degree of inelasticity, and here it fails lamentably. The mating of these two parts of quite definite incompat-

[1] Chairman, Gordon England Co., Wembley, England.

ibility must lead to the same unfortunate result that is witnessed in the human union where incompatibility exists, friction and noise being common to both.

We are, I submit, attempting to unite a rigid and inelastic superstructure to a flexible and elastic foundation, and herein lie all our troubles.

In the past the body builder has discovered that the body he builds, build he never so well, when mounted on the chassis for which it was intended, is subject to relative movement in its parts and these movements in time produce noise. To meet this condition, the body builder has built his body more substantially, but still the problem has not been met, and again he has increased the substance of his structure but mostly without avail. This has gone on until the chassis designer who has been seeking greater performance from his chassis has been staggered at the weight of the superstructure imposed upon the chassis and has objected, and very rightly so. The distracted body-builder has sought for many devices to keep the body quiet, and many ingenious fittings have resulted, so that, in the main, the body-builder has come to rely upon these to keep the bodies in a fairly satisfactory condition during use.

Recently, the automobile manufacturer in the United States (note the cunning introduction of this new being), almost in despair of a solution, has sought for it by making bodies of steel and, as far as possible, jointless so that rattles and squeaks shall thus be further

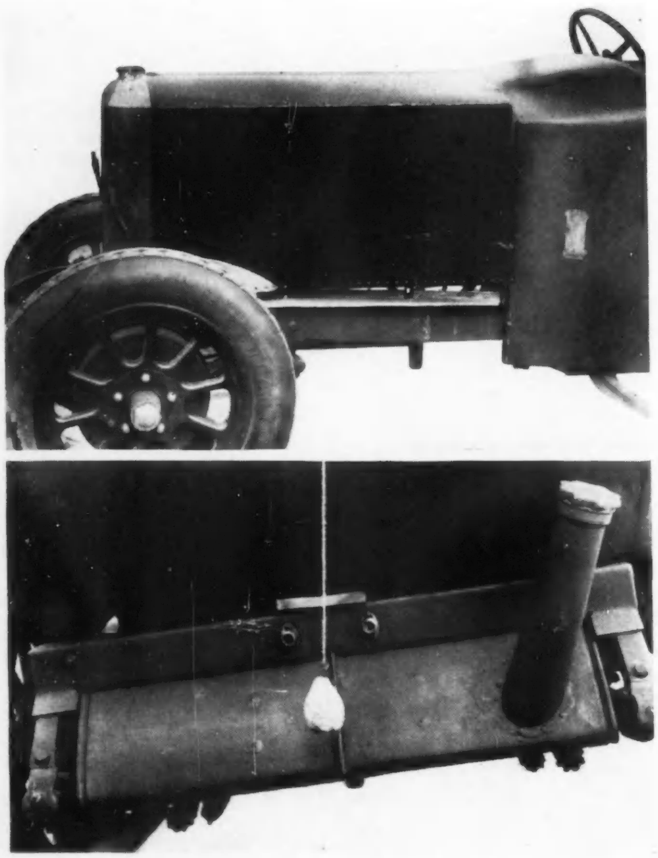


FIG. 1—RELATIVE DISTORTION OF INVICTA CHASSIS FRAME, HOOD AND GORDON ENGLAND BODY

In Upper View Note Displacement of the Hood with Relation to the Frame and Cowl. In the Lower View Note Relation of the Rear End of the Body and the Frame

reduced. This has been partly successful, but a new trouble has been introduced; that is, booming or drumming. Body distortion has been greatly overcome and in fact it is claimed by one manufacturer that the body he builds is so strong that it holds the chassis rigid; and this is regarded as a consideration of which his sales-promotion staff may make capital! Even today the use of the genuine all-steel body cannot be said to be universal in this Country or even approaching it.

This same problem has had to be faced in Europe and the state of things there has been far more acute, owing to the peculiar laws and special conditions which apply to most European countries that manufacture automobiles. These laws and conditions have produced a far smaller and lighter type of automobile than is in common use in this Country and consequently the consideration of the weight of the body structure has been a most important factor. As a result, a very large number of attempts have been made over there to produce a body that is silent and at the same time very light. It would be fair to say that in Europe the body builder or body engineer was forced to give much more consideration than the American body-builder gives to the possibility of entirely new methods of body construction and mounting.

Problems Presented by Demands of Public

Perhaps it will be desirable to summarize at this point the position the world over at the present time before considering the possible lines of escape from the problems confronting us.

Automobile purchasers have become educated, in a very general sense, to the use and understanding of the automobile of today and what they want it to be tomorrow. This means that the public demands now and will be increasingly insistent in the future that the automobile of tomorrow shall, among other things—and I have included only the points that affect the body-builder and the body engineer:

(1) Be more beautiful
(2) Give greater comfort
(3) Be more silent
(4) Have greater body space
(5) Be safe
(6) Stop more quickly
(7) Have projectile-like acceleration
(8) Be more economical in operation

Let us now consider shortly the problems that each of these demands introduces for the body builder or the body engineer.

(1) *Be more beautiful.*—This is likely to cause considerable difficulty because it introduces to a very important degree the possibility of the limitation of methods, materials and structural lines; and, what is perhaps most important, the public's idea of beauty is not necessarily a consideration of true beauty but is the dictates of fashion, which is a very different thing and far more fickle and elusive in its manifestations.

(2) *Give greater comfort.*—Comfort is a state of mind far more than is generally admitted or understood. A car body may give all the appearance of comfort but if in use it does not produce a sense of well-being and peace it has failed, and failed in a way that will react most unfavorably when the owner is making a change of car. The vibrations and drumming so common in many modern bodies produce a distinct sense of

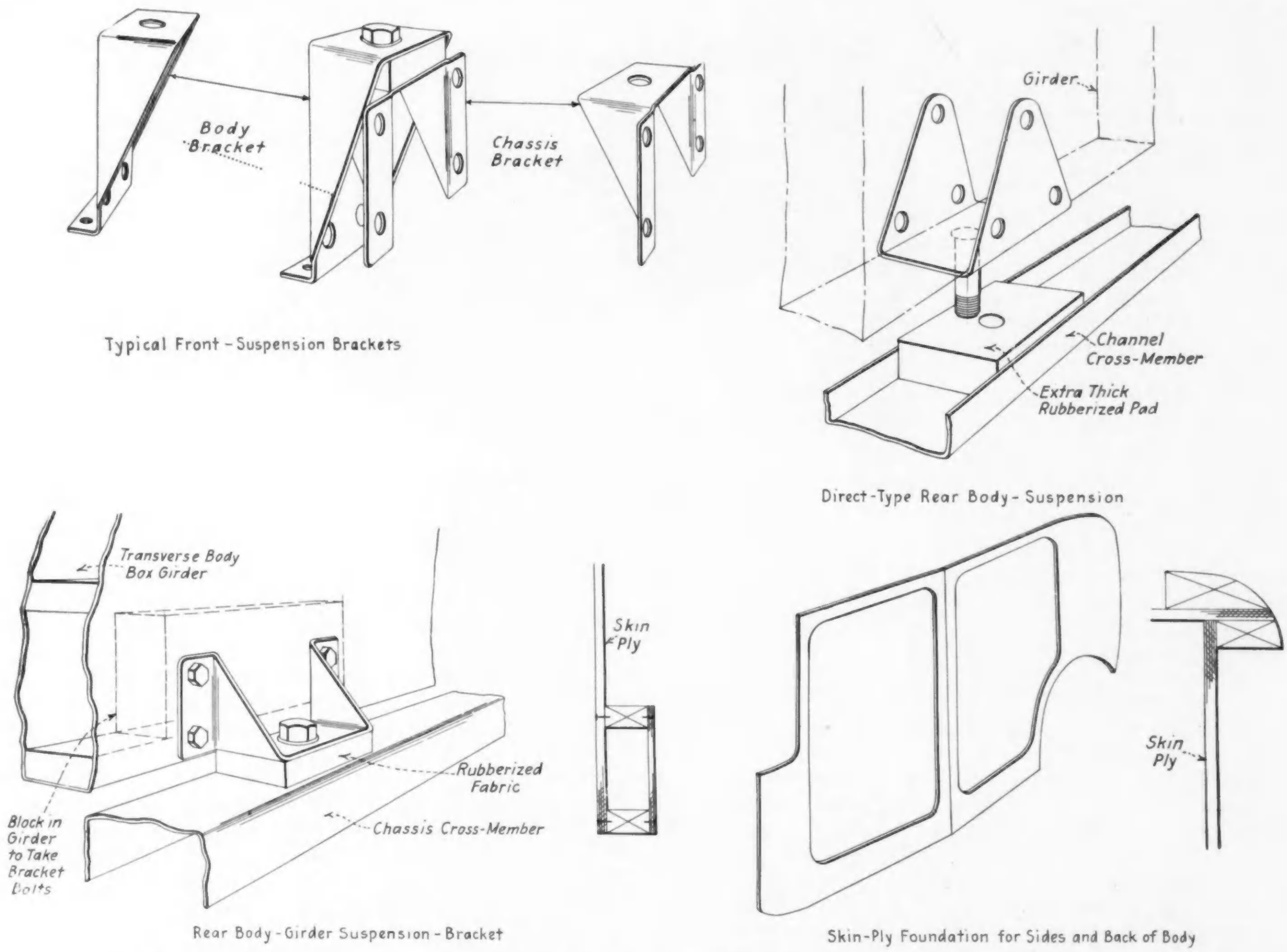


FIG. 2—DETAILS OF GORDON ENGLAND BODY-SUSPENSION BRACKETS AND SIDE AND BACK CONSTRUCTION

discomfort. This failure of the modern body is far more prevalent than is generally admitted.

(3) *Be more silent.*—Those mysterious rattles, squeaks and grunts that sometimes develop so soon are, unfortunately, quite as evident to the user as they are to the engineer, and they cause a disproportionate sense of resentment in the owner's mind.

With the modern body, particularly the type produced in this Country, the curing of these noises is particularly difficult. The reason for their appearance is the "working" that is set up in the body structure by flexibility and elasticity of the chassis, and so no lasting freedom from their appearance can be counted upon.

(4) *Have greater body space.*—The demand for this arises mainly from the natural desire of the purchaser to get more automobile per dollar, but to the body engineer it presents the difficult problem of greater size without increase of weight and the loss of essential rigidity of the structure. The body engineer has to face the fact that increase of size complicates the structural problem to a marked degree, the ideal being as compact a structure as possible.

(5) *Be safe.*—In this Country apparently the industry has dug a pit to its own undoing, as it seems that some of the manufacturers looking for a sales argument have in their national publicity quite unnecessarily emphasized the safety factor and played up to it in many foolish ways. Bodies must be safe, but safety does not surely mean that we must offer massive-looking bodies; they are two such entirely different things. Reasonable strength can be obtained and protection in accident provided for without massiveness by the use of suitable materials and design.

(6) *Stop more quickly.*—The mass of the present automobile presents one of the great difficulties in stopping more rapidly. The chassis designer is steadily cutting weights in an attempt to lower the inertia of the automobile and is calling upon the body engineer to provide his contribution to the general reduction of weight. Weights must be reduced to meet the demand for quicker stopping. A massive body may offer great protection to its occupants in a crash, but it would seem to be much more to the point to have a body that might offer less ultimate protection and a car that is able to avoid such circumstances by reason of its greater ease of control.

(7) *Have projectile-like acceleration.*—All that has been said regarding stopping applies under this heading, for the reduction of mass increases the effective horsepower available for speeding up the car. In these days of almost universal traffic difficulties, acceleration has become of vital importance and its improvement can come in only one of two ways, either by reduction of

the mass of the whole car or by an increase in the effective horsepower of the engine. Anyone who has ever had the experience of driving an identical chassis fitted with a heavy body and then changed over to a light one will agree that the difference in the "feel" of the automobile is remarkable. This has to be experienced to be appreciated.

(8) *Be more economical in operation.* If a body constantly requires attention for rattles and squeaks it will not meet the requirement of the user; if it is unduly heavy it will increase consumption of gas, oil and tires to an extent not usually appreciated. In the case of the tires, this is mainly due to the wear resulting from the greater effort put into them through stopping and acceleration.

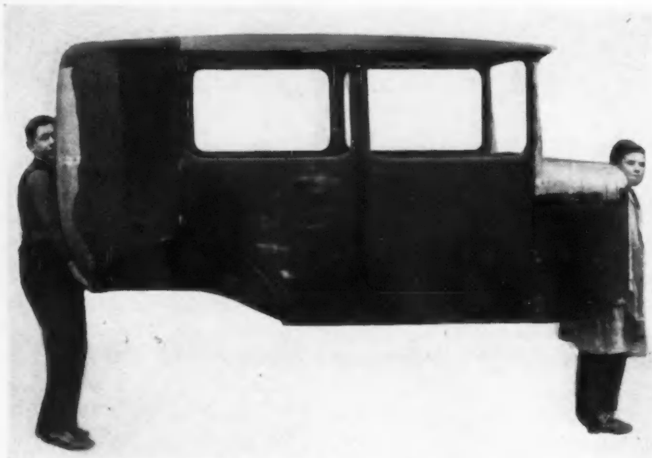


FIG. 3—DEMONSTRATION OF LIGHTNESS OF FIVE-PASSENGER FOUR-DOOR BODY SHELL

Three Classes of Solution Advocated

Certainly we have enough problems to consider under these headings. They are far more acute in Europe than in America, owing to the lighter type of chassis in use, and investigation perhaps started there earlier than here in consequence of that fact.

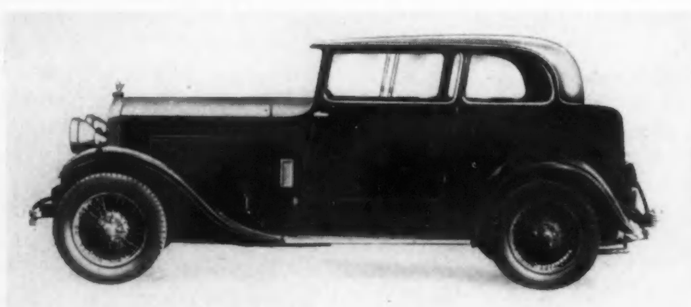
Body engineers in Europe are in almost complete agreement that an automobile chassis *is* a flexible and elastic base upon which to mount the body. This being accepted as the premise, it was natural that those attempting a solution should be divided into three main categories: (*a*) those who claim that, as the base is flexible, the superstructure should be equally flexible; (*b*) those who state that the superstructure must be so strong and rigid that the base will be made rigid in consequence of its attachment to the superstructure; and (*c*) those who seek a solution through the introduction of some form of insulation between the two component parts of the vehicle.

European Example of Flexible Body

C. T. Weymann is the practical pioneer of the first category and great credit is due to him for his work in this direction. His system seemed to offer such an easy solution of the whole problem that he at once caught the imagination of the European manufacturers and public. The bodies he offered faithfully fulfilled his claims; they were light, quiet and very comfortable. In their earlier stages of development they were very limited as to line and style and, while this has been greatly overcome, as was evident in the Weymann bodies shown at the recent Chicago and New York automobile shows, the body, being flexible, had to be covered with a flexible material, and this is regarded by some to be a distinct limitation. Judged by some of the American standards of strength in a body structure, this form of construction may leave something to be desired.

These bodies became a vogue in Europe and are, in my opinion, firmly established, particularly in England. Weymann has many imitators and much work has been and is being done upon the flexible body, in England particularly. Many persons in the United States contend with good reason that, even were the public to accept the appearance of the flexible body, the extra cost involved in handling this material would exclude it from serious consideration for large-volume production. While there may be objections to this system in this Country, it does undoubtedly meet at least five out of the eight points mentioned.

The Weymann system of body mounting consists in a flexible structure rigidly attached to the chassis at several points, the seats and the floor being separated from the body shell.



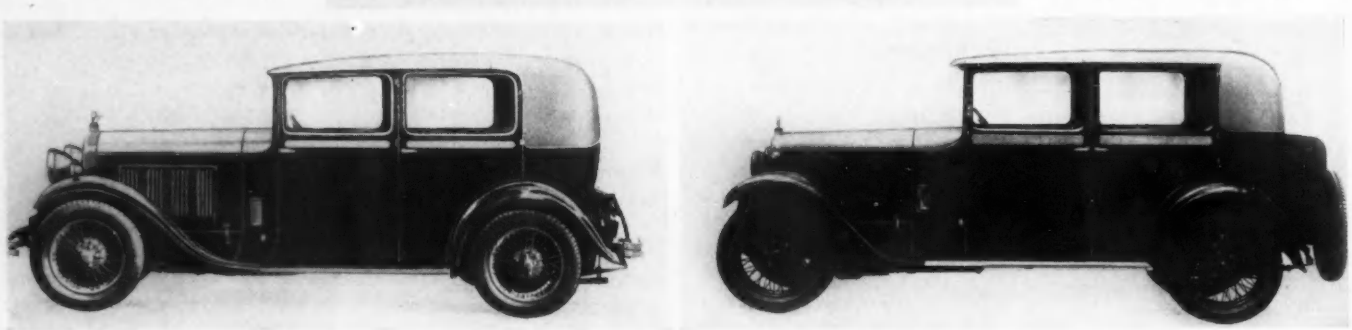


FIG. 4—APPEARANCE OF GORDON ENGLAND BODIES ON ENGLISH CARS

(Top) Morris Isis Six-Cylinder Club Coupe. (Left) Wolseley Isis Six-Cylinder De Luxe Saloon. (Right) Austin 16-Hp. Saloon

The American Rigid Steel Body

In the second category we have the oldest school of body engineers and body builders. They can be dismissed as making no serious contribution by new ideas or methods and as incorporating in an exaggerated form all the evils we have been considering; but in this class we also find the all-steel-body builder, whose engineers have taken the stand that they propose to and can make a body so strong and yet reasonably light that, when attached rigidly to the chassis, it will not only strengthen the chassis but will hold the body and chassis rigid under all conditions. It seems fair to state that in this Country and in Europe the Budd body is the leading exemplar of this thought. It seems probable that only the largest producers could use this system, owing to the high cost of setting-up to produce any given model, but no doubt ways will be found of effecting some economies in this direction.

If weight be a consideration, and I submit that it is, the argument might be advanced that, if it is possible to make a body so strong that it can hold the chassis quite rigid, weight could be saved, for it cannot be the real purpose of a body to hold a chassis rigid. It also seems reasonable to argue that a large hollow structure, such as a body, being subjected to very considerable stresses through the chassis, will develop vibrations and resonance and give a feeling of disquiet to the occupants of the car.

These bodies, however, are making steady headway and appear to offer very real advantages from a production point of view. This system of body mounting can be said to consist of an extremely rigid body attached to the chassis so that the multiple points of attachment are mainly in shear.

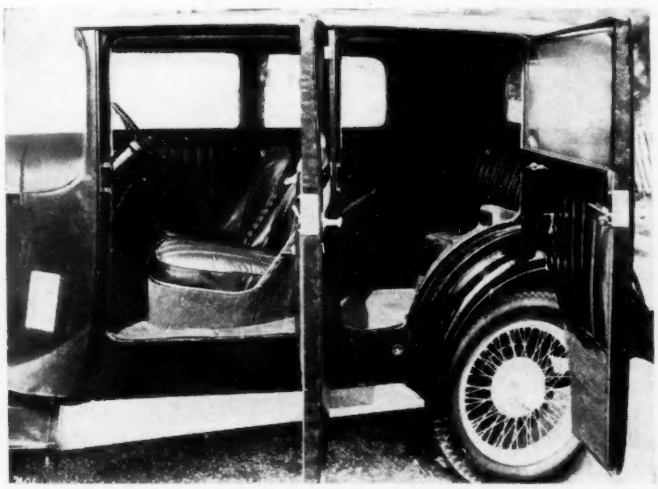


FIG. 5—INTERIOR OF ISIS SALOON BODY

Examples of English Insulated Bodies

In the third category are to be found those who have tried partial and those who have tried complete insulation between the body and the chassis. In Europe the English Daimler Co. has for years used a separate subframe upon which the body is mounted, and this subframe is then mounted by six points of attachment to the chassis, the body being free from the hood dash, an air space being provided at this point. The Lanchester company developed a special cast body-sill of aluminum mounted on several rubber buffers on the chassis. But in all fairness it may be said that these systems, while possessing advantages, have the disadvantage of high cost and only a partial success toward meeting the eight points we have been considering. Several other somewhat similar efforts have been made but none has had any real measure of success.

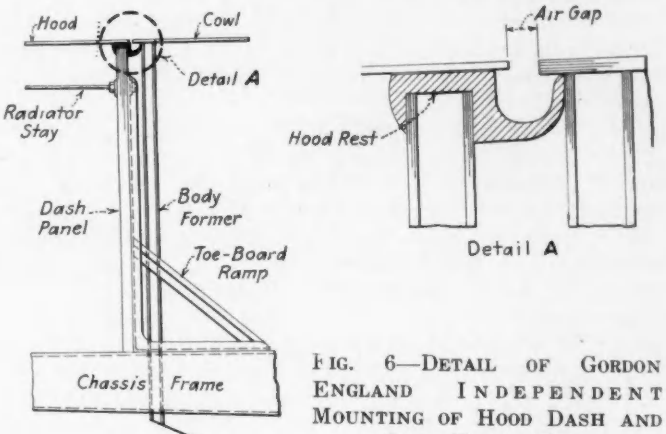


FIG. 6—DETAIL OF GORDON ENGLAND INDEPENDENT MOUNTING OF HOOD DASH AND BODY FRONT END

An Air Gap Is Left Between the Hood and the Cowl and Is Closed by a Rubber Strip, as Shown in the Enlarged Detail at the Right. The Dash Panel Is Held Rigid by Angle Arms Secured to the Chassis Frames, and a Metal Hoop or "Body Former" Holds the Cowl and Front End of the Body in Shape. This Construction Allows Relative Longitudinal and Transverse Movement of the Hood and Body but the Rubber Strip Seals the Air Gap both Water and Air-Tight

Soon after Weymann started upon his experiments, I started my investigations and, agreeing with the premise that all chassis are flexible and elastic, decided to review the whole question in all its aspects. My conclusions were that the function of a body are solely to

(1) Be fashionable in appearance
(2) Offer reasonable protection against accident
(3) Offer complete protection against climatic conditions
(4) Be silent and restful.

These functions show the body in a new light and enable the problem to be attacked from a new angle. I had clearly in mind that, while the essential functions were four, the main conditions to be met were the eight previously listed. The quest of complete quiet had to be borne in mind, the importance of low weight had to be considered, and the flexibility of the chassis had to be countered.

Gorden England Three-Point Suspension

The first step seemed easy. It was obvious that, if the body could be completely insulated from the action of the load to be carried and from the chassis, the problem of noise, the result of distortion and the movements of one kind and another would be solved. The difficulty was to get a body shell that was practically rigid and that would at the same time be light. It was then seen that the body must no longer be considered as a structure composed of somewhat oddly assembled members but should be regarded as a homogeneous unit in which every item performed some part in contributing to the rigidity of the whole.

A structure was therefore devised in which the body shell, which is a sill-less unit, was attached to the chas-

sis at three points with very limited articulation. The hood dash was kept free from the body cowl, as in the Daimler design, and the floor was *unattached at all points vis à vis the body shell* but was rigidly attached to the chassis, and the seats were also attached to the chassis. The result was that the body shell was actually floating unstressed on its three points, for three points constitute a plane, and thus no flexibility or elasticity of the chassis would have any stress effect upon the body shell.

We found that a body of extraordinary lightness could be built and, having ample strength for all requirements owing to freedom from any stressing and consequent working of the body, no relative movement occurred between the body components and therefore complete and lasting silence was obtained. Further, owing to the insulation of the body from the chassis, that restfulness and peace of mind which are so desirable and yet so difficult to obtain are secured.

A number of bodies built on these principles are shown in the accompanying photographs, and details of construction in the drawings. (See Figs. 1 to 6.)

Owing to the rigid nature of the body, any known materials could be used in its construction and most of those generally employed have been used under this system of construction and design. I consider that the ideal material for this system of construction is aluminum, because of its light weight and comparative lack of resonance. A body that weighs 1000 lb. in all steel could easily be made in all aluminum at a weight of 600 lb., and the saving would be actually greater in the final result, because such a saving in body weight would at once make possible a reduction in the chassis weight. Thus the extra cost of material would be more than offset by the price the user would be prepared to pay to get the greatly improved performance.

Aluminum would function perfectly in bodies built under this system because they would never be subjected to racking and working, which does occur in the ordinary body and so makes its use impractical in that case.

My system can be described as a rigid body in which the load and the contact of the floor and passengers are separated from it, the body being mounted at the articulated points of attachment only, the seats and floor being free of the body shell and attached to the chassis.

To summarize, my contentions are that

(1) No real attempts other than those described in the first and third categories have been made to cope with the fundamental difficulty that confronts the body builder and the body engineer.

(2) Basically, one or another of these systems will have to be followed if permanent improvement is to be effected in a radical way in body engineering.

(3) Bodies must be far lighter than they are at present.

It will be a source of intense gratification to me if any remarks I have made contribute even in a small degree to the solution of the body problems.

THE DISCUSSION

CHAIRMAN H. R. CRECELIUS[2]:—I dare say that most of the body troubles today are caused by the flexibility of the chassis, and I think that Mr. Gordon England has gone a great way to correct that with his system of body construction. Those who attended the New York Automobile Salon perhaps saw some of his bodies on exhibition there. I thought they showed that a great deal had been accomplished in eliminating body squeaks and other noises. I made a study of the Gordon England system and think that the pictures presented with the paper showed it fairly well, although the bodies exhibited at the New York and Chicago salons were typically American in design. Mr. England seems to have opened a new line of thought on body construction.

E. H. BRILL[3]:—As the seats are firmly fastened to the chassis and the body floats freely, does not the varying relation of the body to the seats produce a varying relation of the passengers' bodies to the car body of possibly 2 or 3 in. which might result in discomfort, especially of passengers sitting on the ends of the rear seat and coming into close contact with the body shell?

Also would not the fitting of the back of the rear seat against the rear panel result in certain relative motion and cause friction and noises so that possibly a larger body providing clearance for that motion would be required?

E. C. GORDON ENGLAND:—The average amount of normal body movement that we have been able to observe on the normal type of second-class road is about 1/8 to 3/16 in. The passenger of usual size and weight moves as much as 2 in., with ordinary cushion springs. Therefore it is impossible to detect by sensation any movement of the body shell in relation to the seat. We have never had a user of the body criticize it from that standpoint, although about 15,000 of these bodies are in use in England at present. The ordinary jolting on the rear-seat cushion is much greater than any relative movement between the cushion and the body side. The almost universal practice in England is to use two separate front seats which are entirely free of the body side.

To answer the second question, we usually, in the type of bodies I have shown, leave the rear-seat back cushion attached to the shell; the seat cushion alone is separated. We found that was a good compromise, because the back sustains no real load from the passenger, who merely leans against it, and the amount of relative movement has no effect on the passengers. There must be actual vertical relative movement, but the action of the springs of the seat cushion is so much greater that it cannot possibly be noticed.

MR. BRILL:—Sidesway is what I had in mind chiefly. The lower view in Fig. 1 showed that the body on one side was raised possibly 3 in., whereas on the other side it was raised only 1 in. It is conceivable that on a slightly rough road there might be some sidesway that would result in a passenger's shoulders moving possibly 2 in. in relation to the outside of the body.

MR. GORDON ENGLAND:—No, that slide showed a

[2] M.S.A.E.—Body engineer, Lincoln Division, Ford Motor Co., Detroit.

[3] A.S.A.E.—Body designer, Hudson Motor Car Co., Detroit.

really exaggerated case. A quarter of an inch would be the maximum amount of movement of the body of any normal car under any normal conditions.

R. I. SCHONITZER[4]:—The movement of the body in this particular type of construction and mounting seems actually to tend toward balancing the chassis spring reaction on the body and therefore tends to comfort rather than discomfort.

WILLIAM H. EMOND[5]:—Would there be a mechanical disadvantage in making the back seat a part of the body shell?

MR. GORDON ENGLAND:—I do not suppose a diaphragm that would work comfortably could be mechanically constructed. It is far easier from a construction point of view not to attempt those things. Is there an advantage? is the question. The only disadvantage that I can see at the moment is that it would be so difficult to make a diaphragm that would not introduce stress into the body shell, and we want to avoid that.

E. C. GORDON ENGLAND

Possibilities of Light Airplane-Type Construction

WILLIAM G. WALL[6]:—I think that Mr. England is working along the right lines. All chassis engineers are anxious to reduce weights but we cannot cut the weight of the chassis unless we get lighter bodies. The Weymann-body method represents one way of making a light body. Because of its light weight it has certainly shown up well as regards acceleration and deceleration in driving when it is mounted on a good chassis. But there are some objections to the Weymann type of body. I believe Mr. England is coming nearer to solving the problem than most others have come.

Another type of body, however, that seems to me to have great possibilities is that used on the Aero trailer designed by Glenn H. Curtiss. Those bodies are rather long and are attractive when attached to the rear of a roadster. They generally contain six or eight wicker chairs. They weigh only about 1200 lb. and ride very comfortably. What is most important, they are extremely rigid. This result is accomplished by following airplane-fuselage practice, using cross-rods to secure stiffness, so that the posts and other compression members can be made comparatively small and the covering can be fabric or metal if desired. The entire superstructure of the trailer is rigid and at the same time light.

A superstructure of that type, mounted in some such manner as Mr. England proposes, seems as if it might offer a way of getting light bodies. Many difficulties stand in the way of a construction of that kind, but it is possible to build bodies on that principle, and it would be a great relief to those who are endeavoring to design engines to develop more power to take care of the increased weight of the present bodies if the bodies were made lighter.

Stiffening Chassis Overcame Many Troubles

WILLIAM E. ENGLAND[7]:—I have felt very sorry in the past for the majority of body builders who have had to build bodies for some of the flexible chassis. I cannot understand how a body builder can design a body that will not squeak when mounted on some chassis.

Shortly after four-wheel brakes and balloon tires came into use, the Stearns company had a chassis that possessed the usual characteristics of radiator wabble, shimmy and tramp, wheel kick and all the undesirable front-end phenomena. In the road test we had about as many men as we had road testers trying to get the squeaks out of the various bodies. The situation became so bad that we set up a floor dynamometer which subjected the front end, then the rear and finally the whole chassis to severe vibration and torsion. By that means we tried to locate the cause of the trouble, but with the body on we could not tell much about it. After taking the body off, we observed that the side rails of the frame were attached to the cross-members by flanges and webs in such a way that the whole chassis twisted like rubber.

With a condition like that it is impossible to maintain a squeakless body. We spent about $60 on each frame to remedy that condition, but because of the construction of that chassis it was not possible wholly to eliminate the trouble.

About three years ago, when designing a new chassis, we first laid it out on the drafting-board as we thought it should be. Then we built two samples and put them under a stress on the floor dynamometer, the front and rear wheels separately. We twisted the chassis severely, but virtually all the movement was being taken up in the springs, which distorted and twisted sidewise and up and down. This chassis was laid out with 6 in. of spring clearance at the rear and 4¾ in. at the front, and long, flexible springs were used.

When the body was mounted on that chassis only one squeak man was needed for the whole road test, and body squeaks were noticeably absent. I drove one of those cars approximately 35,000 miles, including trips to Quebec, Canada, and to San Diego, Calif., and never developed any squeaks in the body. We had more trouble keeping the squeaks out of the car springs, even though they were covered and lubricated. Radiator movement also disappeared and there was no wheel kick, shimmy or tramp, or radiator or transmission movement even when driving over rough roads at high speed, which no sane person would attempt.

I think that this whole problem is being attacked from the wrong end and that the chassis should be made rigid. I do not mean that a paper-shell body should be put on top of it so that the body itself will move around. The cars in the shows this year revealed that the chassis are being stiffened, and it is surprising how little extra metal and how little more weight are needed to stiffen up some chassis.

MR. GORDON ENGLAND:—That may be an ideal condition which one or two chassis manufacturers, in their kindness of heart, will observe, but I doubt whether they will adopt that policy. The Lanchester chassis, which is very rigid and most wonderfully equipped with torque members to take distortion stresses, definitely

[4] M.S.A.E.—Body engineer, in charge of body engineering, Auburn Automobile Co., Auburn, Ind.

[5] M.S.A.E.—Body engineer, head of department, H. H. Franklin Mfg. Co., Syracuse, N. Y.

[6] M.S.A.E.—Consulting engineer, Indianapolis.

[7] M.S.A.E.—Chief engineer, F. B. Stearns Co., Cleveland.

went out of shape about ½ in. when subjected to an 18-in. distortion. A half inch is enough to wreck the finest body that has been made. A condition will arise sometimes that will subject a frame to that amount of distortion, and when that occurs the body is started on its downward path to ruin.

WILLIAM E. ENGLAND:—We have jacked up one rear wheel 12 in. and a diagonally opposite front wheel of that Stearns chassis the same amount, and the doors of the body could be opened and shut without trouble.

Articulation of Dash and Body

MR. BRILL:—Can Mr. Gordon England show us on the blackboard exactly how he mounts the radiator and especially the front or cowl board to the frame so as to hold it fairly rigid and at the same time leave the body free to move in relation to it?

MR. GORDON ENGLAND:—In the case of the Chrysler and the Buick cars, we have cut the original metal cowl right off. Then we stiffened the dash with an angle and bridged it down to the ramp for the toe-bolts. That, we found, is sufficient for all practical purposes; it allows a certain amount of body motion, as there is no connection between the dash and the body. If an air space is provided for the body to move across, the body and the dash can move toward or away from each other when the frame twists. By that construction the two movements, which are out of harmony instead of being taken together, have a cancelling effect, and when the radiator and hood are separated from the body they do not vibrate much. That is true of the Chrysler, the Buick and the Erskine, for which we built bodies in quantities in England.

Fig. 6 shows at the left the relation of the dash and hood to the cowl, metal "body-former" and the toe-board. The body stops free at the body-former, which is a metal hoop that keeps the front end in shape. Angle irons rise from the side-frame members back of the dash panel to stiffen it against all ordinary distortion. Detail *A*, shown enlarged at the right in the drawing, shows the air gap between the hood and the cowl. The shaded portion is a drawn-aluminum section that is screwed onto the dash panel and carries a rubber strip that presses against the body-former. The cowl is extended over this and leaves an air gap of ¼ to 3/16 in. between the cowl and the dash, according to the size of the car. The rubber strip is made of a good quality of rubber and of a form that when inserted bends or folds up between the dash and the body-former hoop, making an air-tight and water-tight seal all the way around between the hood and the body. At the same time the gap and the rubber allow all the necessary transverse and longitudinal movement between the body and the hood. This is a satisfactory system and gives no trouble.

H. R. CRECELIUS

Vicious Circle of Increasing Weights

HERBERT CHASE[8]:—It seems to me that in this Country we have traveled more or less in a vicious circle of increase in weight. When we consider that we buy most of our materials on a weight basis and that the cost of materials often runs as high as 80 per cent of the cost of the car, we see that the importance of weight saving is very great. What we have done, in effect, is to start with a moderately light chassis, put on a body that was quite heavy, then found that the chassis and body were not sufficiently stiff, and therefore added weight to both the chassis and the body to make them stiff, thereby further increasing the weight. Then we found that the engine was not large enough for the car to perform satisfactorily, and so put in a more powerful and heavier engine.

When we added power enough to secure proper acceleration and brakes adequate to give sufficiently rapid deceleration, we found that the body was not strong enough to resist the stresses involved, so we further strengthened the body, every time adding weight and keeping on in the vicious circle. We have gained very rigid structure but one not adapted to withstand, without danger of fracture or failure at some point, the stresses imposed when a car must pass over very rough roads that still abound.

If we could attack the problem from the other angle, as Mr. England in England and Mr. Weymann in France have done, we would start with a light, flexible body that would not be injured by conditions encountered in service. Then we could use a lighter chassis, engines would be sufficiently powerful, and we would not have to increase weight. Thus we would reverse the order in our circle so that the tendency would be toward lightness, better acceleration and deceleration and lower total cost. There are great possibilities in this method of attack.

Specific Cases of Weight Saving

L. C. HILL[9]:—How does a body of this construction for a five-passenger sedan compare in weight with that of the conventional construction in the same model? I assume that you have built models for a given chassis for which you have the relative body weights.

MR. GORDON ENGLAND:—We saved exactly 200 lb. on the Erskine body that we built for the Studebaker Corp. in England. That body was slightly larger in cubic capacity than the standard Erskine body. Otherwise it was the same; we used exactly the same fenders, the same hood and the metal dash, which we cut off from the cowl. We put safety glass in all the bodies, as against the plate glass that is used in the regular body, and we used real leather in the upholstery. With those changes we saved exactly 200 lb.

We also made the Chrysler bodies slightly larger than the standard job, again using safety glass instead of plate, leather in place of cloth, the same fenders and the same hood, and we saved 380 lb. The whole saving was in the body. These two examples will give a fair idea of the savings we have been able to achieve.

In the heavier types of body in England, such as those fitted on the Rolls-Royce, which we call an interior-drive limousine with a partition, we were able to save 810 lb. in the weight of the standard bodies with a body of equal dimensions to those offered by our competitors. We used exactly the same specifications. The panels were of aluminum. That particular body

[8] M.S.A.E.—Associate editor, *American Machinist* and *Product Engineering*, New York City.

[9] M.S.A.E.—Vice-president and general manager, Dietrich, Inc., Detroit

was built as an experiment. The owner asked us to guarantee very light weight. He has used the car for 50,000 miles on Continental roads and it was still free from rattles at the time I left England.

CHAIRMAN CRECELIUS:—I believe that you had one of your bodies on the Packard all-weather car at the automobile salons. Have you any idea how that compared with the regular composite body?

MR. GORDON ENGLAND:—The Packard people said we had saved 400 lb. on that. It was a big seven-passenger car. Frankly, I would not call that a good example of what we can do. It was designed entirely in this Country and many things that I should have cut to ribbons were left in the conventional proportions.

Turn-Under and Side-Sweep Retention

QUESTION:—Is it possible to use your construction and still retain the turn-unders and side-sweeps that we use in the present cars?

MR. GORDON ENGLAND:—Yes, it is simply a question of adapting the design. I do not think we would get as much turn-under as you do in some of your jobs if you were not prepared to do what we do in Europe; that is, extend the door down to the running-board. But if you are prepared to adopt that style of construction and do away with what we call the valence, there is no reason why you should not bring the turn-under in as you do and make the girder the reverse way.

MR. BRILL:—In the designs that you have shown the turn-under has been very negligible.

MR. GORDON ENGLAND:—That is true. We do not complicate our lines more than the public insists upon. As turn-under in Europe is not a requisite, thanks mainly to the efforts of Mr. Weymann, who was able to convert the public from turn-under, we have followed suit.

Attachment of Running-Board and Fenders

MR. SCHONITZER:—Will you describe the best means you have found for attaching the running-board and fenders, which have so much to do with the subject?

MR. GORDON ENGLAND:—There is a more or less natural division with our type of body. The rear fender is mounted on the body and is entirely separate from the running-board and the front fender, which, in turn, are entirely separate from the body. We allow an air space all the way along between the two. When that is done, the fender and running-board squeaks disappear, because a great deal of the stressing to which those parts are ordinarily subjected is removed. The racking in the whole length of the complete car is a very serious contributor to most of the fender and runningboard squeaks. When the back fender is separated, most of them disappear. We have had no trouble in keeping them out of the Chryslers and Buicks and Erskines that we have made.

CHAIRMAN CRECELIUS:—What influence has your design on body drumming or booming? Does the body diminish the chassis noises?

MR. GORDON ENGLAND:—We claim that the noises are diminished to a marked extent; in fact, when the first Model-A Ford came out, it was subject to drumming, but experimental bodies that we built were extraordinarily successful in overcoming that particular difficulty.

CHAIRMAN CRECELIUS:—Is that accomplished by the insulation of the body from the chassis in your type of body construction?

MR. GORDON ENGLAND:—Yes.

Movement Allowed by Body Supports

GEORGE J. MERCER[10]:—How do you fasten the body on the three supports? Do you fasten it rigidly at the front? Does the way in which it is bolted at the front and the rear allow any flexibility in the mounting and how much play do you allow for it? Is the support on which the body is fastened at the rear raised above the chassis frame so that there is a possibility of quick movement one way or the other?

MR. GORDON ENGLAND:—We usually allow 7/8-in. movement where the corner passes over the chassis frame. We have found that allowing for a relative movement of 7/8 in. on each side, or a total of 1 1/2 in., is ample.

MR. MERCER:—Do you use a rubber packing?

MR. GORDON ENGLAND:—We use a pad 7/8 in. thick which is made of lamination upon lamination of fabric material interposed with rubber. It has enough give so that it will absorb any movement of the body relative to the chassis that we regard as necessary. We try to limit it to a certain extent so that it will act rather like a shock-absorber.

[10] M.S.A.E.—Detroit.

Suppressing Ignition-Interference on Radio-Equipped Aircraft

By E. A. Robertson[1] and L. M. Hull[2]

St. Louis Aeronautic Meeting *Illustrated with* Charts, Photographs and Drawings

THE AUTHORS say in part that although it has meen recognized for many years that electrical ignition systems on airplane powerplants are a prolific source of disturbances tending to prevent the successful reception of radio signals, the serious and intensive development of methods of suppressing such interference is a comparatively recent undertaking. This arises from the fact that only in recent years has special significance been attached to radio operations with limited collecting structures or antennas, over such distances that the signaling waves intercepted by these antennas are relatively weak. They then outline the systems in which interference is present and discuss how it can be suppressed.

Modern restrictions upon the receiving systems on both commercial and military airplanes have established a set of conditions which focus the designers' attention upon the complete suppression of electrical radiations from the ignition system, and these restrictions are both physical and electrical. Physically they include the elimination of the trailing wire and the use of fixed vertical or horizontal antennas positioned without regard to their proximity to the powerplant. The methods of interference suppression in vogue today are the results of wholly empirical and, in many cases, unscientific development, the authors assert.

After discussing the nature of the interference, the authors discourse on the suppression of ignition interference by means of shielding. A constructive tendency in recent shielding development, they say, is the extension of the idea that a shielding system which holds together under service conditions, if intelligently designed, may be just as successful in keeping water, oil, and dirt out of the ignition as it is in keeping noise out of the radio. The remainder of the paper is devoted to a discussion and illustrations of various shielding systems now in commercial or experimental use, which are designed for *complete* housing of all important current-carrying circuits on the airplane engine.

In the discussion, the belief is stated that no shielding at present has fully met the day-in-and-day-out grind of transport operations, and that it probably will develop for some time yet and will be evolved slowly. Tests of radio equipment made in a four-place cabin plane, having a J-5 nine-cylinder engine that was not shielded, are described. Doubt is expressed whether a worthwhile distinction will be made between the necessary shielding for long-wave and short-wave reception in the plane.

The remainder of the discussion is largely concerned with details regarding the merits of vertical versus horizontal antennas, sensitivity of receiving sets, the best types of mast and their manner of mounting, and the like.

ALTHOUGH it has been recognized for many years that electrical ignition systems on airplane powerplants are a prolific source of disturbances tending to prevent the successful reception of radio signals, the serious and intensive development of methods of suppressing such interference is a comparatively recent undertaking. This arises from the fact that only in recent years has special significance been attached to radio operations with limited collecting structures or antennas, over such distances that the signaling waves intercepted by these antennas are relatively weak. The increased interest in the suppression of ignition interference can best be rationalized by taking a hasty glance at the general characteristics of those radio installations in airplanes wherein ignition interference is present.

A typical aircraft radio-system permitting tolerable service in the presence of full ignition-interference consists first of a radio ground-transmitter—preferably emitting continuous-wave code-signals—operating into an efficient open antenna and establishing intense radio field-strengths throughout the working range; second, a trailing-wire receiving antenna, entering the airplane at a point as remote as possible from the engines, and so long that the most effective collecting portion is from 25 to 150 ft. from the fuselage; third, a radio receiver which is just sensitive enough—either by operating adjustment or by initial design—to convert the signal waves into audible signals. With such a system there may be a useful service range of distance from the transmitter, throughout which the currents induced in the antenna by the radio signaling-waves are sufficiently large, compared with those excited by the electrical radiations from the powerplant, to permit interpretation of the received signals.

But modern restrictions upon the receiving systems on both commercial and military airplanes have established a set of conditions which focus the designers' attention upon the complete suppression of electrical radiations from the ignition system. These restrictions are both physical and electrical. Physically they include the elimination of the trailing wire, and the use of fixed vertical or horizontal antennas positioned without regard to their proximity to the powerplant. Electrically they include (*a*) operation from directive transmitters, that is, radio beacons, which at their present stage of development radiate less efficiently than standard open-antenna transmitters for a given expenditure of power; (*b*) operation from conventional non-directive transmitters over distance ranges which are comparable with

[1] Consulting engineer, Detroit, Mich.

[2] Vice-president, Aircraft Radio Corp., Boonton, N. J.

the ranges of reception obtainable in "quiet" locations on the ground; (*c*) reception of telephone signals of high intelligibility in the airplane; and (*d*) use of high transmission-frequencies, that is, short waves, located in a portion of the frequency spectrum where the average airplane ignition-system is a particularly efficient radiator of disturbances.

The methods of interference suppression in vogue today are the results of wholly empirical and, in many cases, unscientific development. No pretence will be made in this paper toward an exact analysis of the problem or a complete and logical solution thereof. We shall merely attempt to describe briefly certain methods characteristic of current practice and to call attention to those features which most urgently require investigation.

Nature of the Interference

Electrostatic discharges and interruptions or variations of electric current anywhere in the vicinity of a radio receiver produce electric fields which are converted by the receiver into noises interfering with the radio signals. In extreme cases these impulses may so paralyze the vacuum tubes of the receiver that it does not respond at all to the desired signaling currents. The impulsive radiations from an airplane engine, if unrestrained, present just such an extreme case with respect to the high-sensitivity receivers developed during the last few years for airplane use.

From a radio viewpoint, the average ignition-system emits a complicated electrical disturbance which is distributed throughout the frequency spectrum all the way from the average spark-frequency to the high radio-frequencies of free oscillations in the high-tension leads. The radio receiver, which includes a chain of selective circuits more or less sharply tuned to a single frequency, responds in a similarly complicated fashion. The oscillatory circuits are shock-excited by fields emanating from the impulsive currents accompanying the spark. Short-wave receivers probably also respond directly to the high-frequency free-oscillations.

In an unshielded system, the disturbance is not localized in any particular section of the ignition system. The high-tension circuits react on the low-tension circuits which, in turn, throw out disturbances. Exposed wiring in the craft, metal fuselage-members, and the metal walls of the engine itself, may act as secondary radiators. There are no conclusive indications of a major difference in the susceptibility of long-wave receivers, above 500 m. (1640 ft.), and short-wave receivers, below 200 m. (656 ft.), to interference from the existing engines.

It is probable that a short-wave receiver will pick up interference from an exposed engine at a greater distance than a long-wave receiver of equal sensitivity, although much inconsistent and contradictory evidence has been collected on this point. For example, conspicuous "shadow effects" may occur in observations made with a receiver which responds only to frequencies around 6000 kilocycles, which disappear entirely at 300 kilocycles. For a certain location of the receiving antenna, the ignition noise from a partly shielded engine may be imperceptible at one frequency and tremendous at a second frequency remote from the first. Then either the shielding or the location of the antenna may be altered so that the conditions are entirely reversed.

From these general considerations it may be inferred that the most logical attack on the whole problem is the straightforward scheme of housing all elements of the ignition system in metal and suppressing every disturbance at its source. If this plan is pursued, it is obvious that the most important considerations are the structural design of a housing system which will remain physically closed over long periods of operation, and the maintenance of reliable ignition and engine operation.

Enough progress along this line of attack has already been made to indicate that the ultimate outcome will be the provision of shielded engines which are better protected from the elements and actually more reliable than engines without shielded ignition-systems. But the universal prejudice against major design-changes which originate in requirements outside the engine, still stimulates an occasional attempt at preventing or neutralizing ignition interference by indirect methods. Before passing to a detailed consideration of ignition shielding, the more important proposals of this sort are described herewith.

Indirect Suppression of Interference

A number of attempts have been made to modify the character of the sparking currents in the spark-plug leads so as to reduce their effects on a radio receiver. Two years ago one of the authors obtained from the French Air Ministry specifications for resistance loading-units designed for insertion in series in the spark-plug leads which had been used on a limited scale in France, although the scheme is probably much older. The advisability of such a method is questionable from the viewpoint of engine performance. More recently this method has come into vogue in connection with engines on radio-equipped automobiles, where engine reliability is at least not a matter of life and death.

What actually occurs when resistances are inserted in series with the spark-gaps is apparently a suppression of free oscillations in the high-tension cables. But the low-frequency impulses are still present so long as the spark-plugs function at all. The net result is that the level of ignition interference in a nearby radio receiver is perceptibly lessened by the use of resistances; but complete suppression of the disturbance is never realized, even if the resistance is increased to a point at which no sparking occurs.

Another scheme of this nature involves the use of inductance coils in the high-tension leads, the idea being to smooth out sharp discontinuities in the current wave-form and displace the principal frequency-components away from the frequencies used in radio reception. A certain amount of development work has been done on this scheme in Germany, in America, and probably elsewhere, but there is no evidence at hand indicating that consistently useful results can be obtained.

The general idea of neutralizing ignition-disturbances by electrical circuits associated with the radio receiver has been advanced from time to time. Ignition discharges are similar in their effects on reception to atmospheric disturbances, or "radio static." The neutralization of static has been the aim of much fruitless research since the first radio message was sent. The most rational schemes proposed for static suppression involve the establishment of two receiving-systems which receive substantially the same amount of static, one of which discriminates against the desired signal.

The electrical or acoustical outputs from the two systems are then combined differentially, and the static is neutralized, at least in theory, leaving a residuum of intelligible radio signal. One reason why this idea has never been conspicuously successful in practice is that atmospheric static is seldom localized; it may come from all points of the compass in a short space of time, and it is practically impossible to maintain two receiving-systems each of which preserves a constant signal-static ratio.

But this general mode of attack seems rational in the case of a periodic disturbance originating in an engine which is fixed in position with respect to the radio equipment. There are at least two flaws in this reasoning which become painfully apparent on applying the general scheme. First, the sources of the disturbance are not thoroughly localized in the case of an unshielded engine. Further, although the ignition interference has a general periodic-character, experimental evidence indicates that the phases and amplitudes of the various frequency components in each spark vary from one spark to the next in the same plug and are substantially affected by engine speeds to such an extent that a precise balance or neutralizing effect with any electric-circuit combination is extremely difficult.

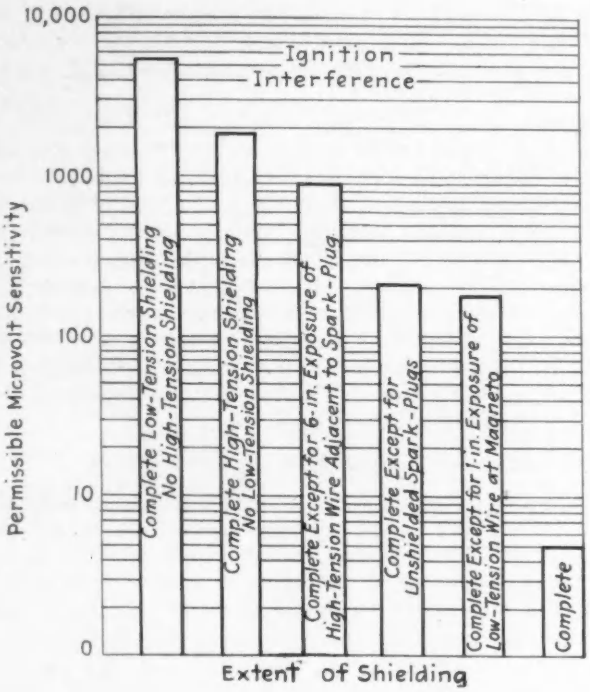


FIG. 1—CONTRIBUTIONS OF THE VARIOUS ELEMENTS OF AN AIR-COOLED AIRPLANE-ENGINE TO THE TOTAL IGNITION-DISTURBANCE PRODUCED IN A TYPICAL RADIO INSTALLATION

The Relative Magnitudes of the Various Factors Contributing to the Total Disturbance Are Characteristic of Radio-Beacon Receiving-Equipment Installed on a Single-Engine Plane and Employing a Mast Antenna. The Ignition-Interference Levels Are Plotted Vertically on a Logarithmic Scale, for Various Conditions of Shielding

One of the authors has experimented with an airplane receiving-system involving two antennas, one of which is exposed to the radio-signal field and to the ignition disturbance, the other being protected from the radio signal but exposed to the ignition system. The outputs from the two antennas are combined in a suitable circuit for adjusting their relative amplitudes and phases, and fed into the radio receiver. A perceptible improvement in the over-all ratio of signal to interference can be obtained, for a given frequency of reception, but no results comparable with those produced by straightforward ignition-shielding have thus far been realized. Further development work of this sort along these lines is not a hopeless undertaking.

Shielding To Suppress Interference

As a general rule, any metal fitting, cowling or housing, which interposes a physical screen between a current-carrying lead in the ignition system and the radio antenna or receiver circuits tends to reduce the ignition interference. A completely cowled water-cooled engine may emit so little electrical disturbance that radio reception over long distances is possible without special shielding. A partly cowled air-cooled engine may offer so little interference that the proper economic balance between thorough shielding and the provision of strong, and therefore expensive, radio signals is a real problem. Hence it is now common practice to shield just enough of the various elements of the ignition system to allow tolerable radio service for individual sets of operating requirements, on the theory that if the safety factor of a completely shielded system is known, the factor of a half-shielded system is half known.

The contributions of the various elements of an air-cooled airplane-engine to the total ignition-disturbance produced in a typical radio installation are shown graphically in Fig. 1. Here the relative magnitudes

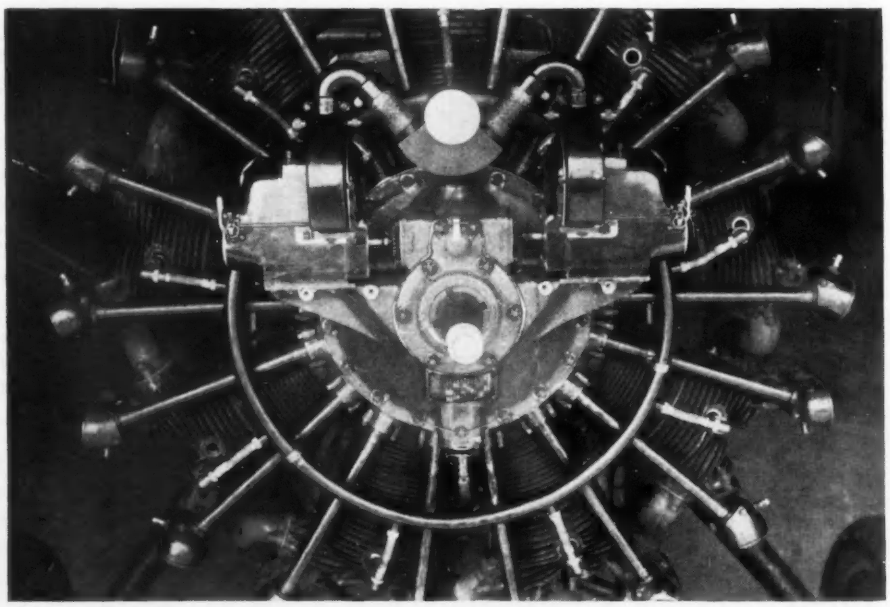


FIG. 2—SHIELDING ON A WRIGHT J-5 ENGINE

This Design Was Developed by the Bureau of Standards in Cooperation with the Wright Aeronautical Corp., the Breeze Corp., the Scintilla Magneto Co., and the B. G. Corp.

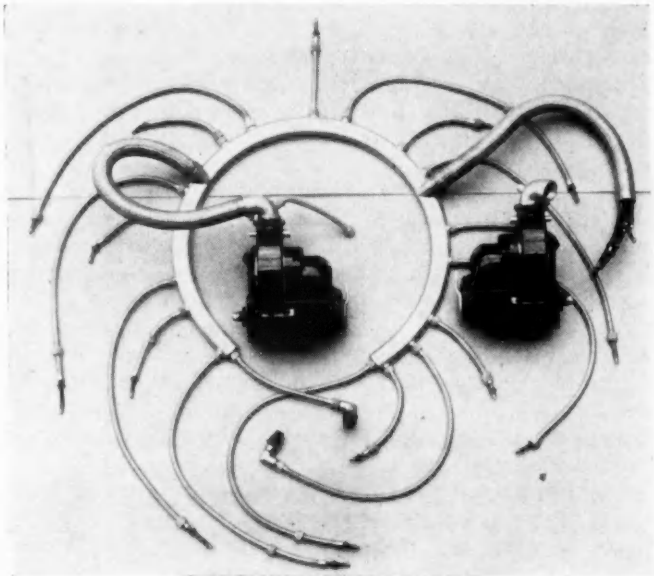


FIG. 3—REFINEMENT OF THE DESIGN SHOWN IN FIG. 2
The Main Manifold Is a Rigid Tube from Which Radiate Flexible Metal Tubes Having Packed Joints between the Manifold and the Spark-Plugs

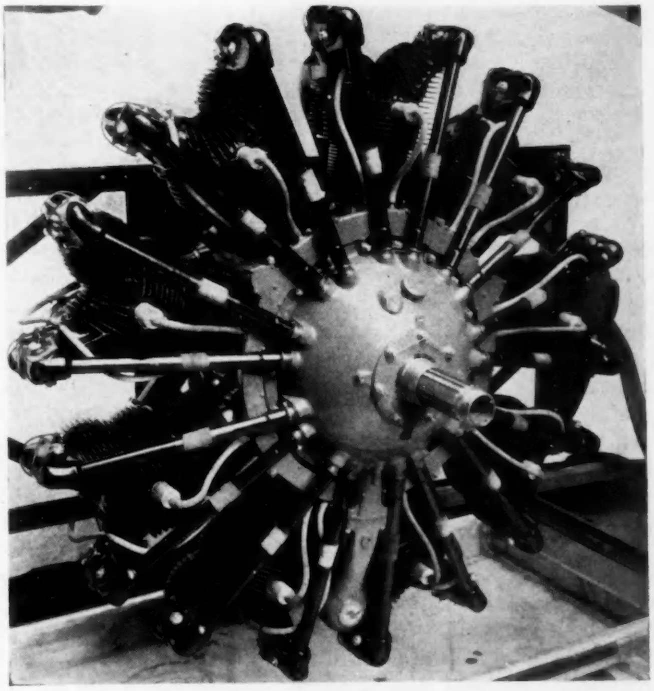


FIG. 5—SHIELDING APPLIED TO A PRATT & WHITNEY ENGINE
It Consists of a Cast-Aluminum Ring Fitted with a Cast-Aluminum Cover

of the various factors contributing to the total disturbance are characteristic of radio-beacon receiving-equipment installed on a single-engine plane and employing a mast antenna. The ignition-interference levels are plotted vertically on a logarithmic scale, for various conditions of shielding. The actual values of the various ordinates are presented in microvolt sensitivity of a radio receiver in which the ignition interference is just audible to an experienced observer; thus, the heights of the columns are proportional to the interference voltage impressed on the receiver under various conditions of progressive shielding.

Credit for the increased activity in ignition shielding during the last few years should go to the personnel of the Engineering Division of the Army Air Corps at Wright Field, who have, excepting the Bureau of Standards, made a more complete study than anyone else of the relation of shielding to engine reliability and performance. Approximately 15 per cent of all Army Air Corps engines have been ordered with shielded ignition. As an example, the Curtiss No. 1570 engine is equipped with a

FIG. 4—MAGNETO HAVING THE SINGLE-OUTLET TYPE OF SHIELD

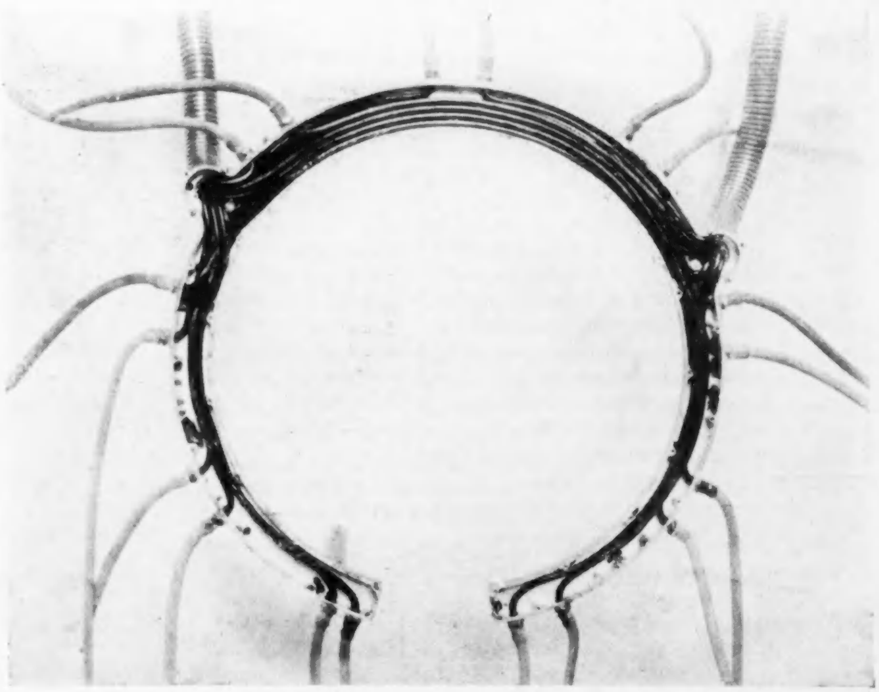


FIG. 6—ASSEMBLY OF THE ENGINE SHOWN IN FIG. 5 WITH THE COVER REMOVED

shielded Scintilla double magneto and separate distributors. Wires are partly shielded by the standard wire conduits. Those parts of the wires extending beyond the conduits have sections of tubular copper braid drawn over them. The whole is completely bonded together by wiring and soldering the braid to the conduits. No shielding at the spark-plugs is used.

The Bureau of Standards was among the first to investigate the subject. One of the designs appears in Fig. 2 on a Wright J-5 engine. This design was developed by the Bureau of Standards in cooperation with the Wright Aeronautical Corp., the Breeze Corp., the Scintilla Magneto Co. and the B. G. Corp.

Fig. 3 shows a refinement of this design. The main manifold is a rigid tube from which radiate flexible metal tubes. The tubes between the manifold and the spark-plugs have packed joints. The spark-plugs are of the angle-type shielded "B.G." model. The application of this design is made by the Breeze Corp. The Scintilla magnetos have the single-outlet type of shield similar to that shown in Fig. 4.

Another example of this type of shielding has been designed by the Universal Aircraft Corp. Its application to a Pratt & Whitney engine is shown in Fig. 5. It consists of a cast-aluminum ring fitted with a cast-aluminum cover. Fig. 6 shows the assembly with the cover shown in Fig. 5 removed. To shield the wires between the ring and the plugs, a metal braid is drawn over them and over that a rubber tube to exclude oil and water. It is understood that this braid-and-rubber tubing is to be replaced with a very light flexible metal-tubing. The magneto shields and those over the spark-plugs were built by the Universal Aircraft Corp. Other developments along these general lines have been devised, but they are omitted because it has been impossible to obtain accurate data on their design and performance.

Factors Considered As Most Important

In considering this subject from all angles the points considered by the authors to be the most important are set down in what is considered to be their relative merit.

(1) *No disturbance of the normal operation of the engine.*—The transport operator requires, more than anything else, reliability of the power-plant. Any attempt at ignition-interference suppression which does not recognize an essentian division of responsibility between the engine designer, the radio designer, and the airplane designer, can supply at best only a partial solution of the problem.

(2) *Reliability of radio communication.*—This feature must be recognized at the outset as of secondary importance compared with item (1).

(3) *Ease of servicing.*—This is a question of prime economic importance to the operator.

(4) *Cost and weight.*—These items should receive attention only after the foregoing requirements have been met.

Requirements of the Engine Builder

The engine builder requires shielded ignition-accessories which present no hazard to proper engine performance. Rather, engine performance should be improved through such desired features as added waterproofing and mechanical protection of the ignition units. A constructive tendency in recent shielding development is the extension of the idea that a shielded ignition-system which holds together under all service conditions may be just as successful in keeping water, oil, and dirt out of the ignition system as it is in keeping noise out of the radio. The engine builder should be able to purchase shielded ignition-units designed and built to a standard specification.

It should be possible to mount or to remove the shielded ignition-units readily; without injury to them or to the engine. Cost should be as low as is consistent with the foregoing considerations. Weight should be kept to the minimum. As any shielded ignition-system weighs, in its complete form, less than 10 per cent of the total engine-weight, the saving in weight between the lightest and the heaviest system so far produced represents a 1-per cent difference in weight in any engine of average size.

The radio-equipment designer having set the requirements, it is the duty of the manufacturers of spark-plugs, wire and magnetos or timer distributors to approach as closely as is possible to these requirements, keeping in mind the demand for engine reliability.

Foundation for a Universal Specification

The first attempt to draft complete shielding specifications for ignition systems was made by the Bureau of Standards, June 6, 1929. The specification drawn by that Bureau can well form the foundation for a universal specification. The following salient points appear in it.

(1) The entire ignition system must be completely encased in metal.

(2) The conductivity of the shield must be as high as possible.

(3) Only the highest grade of insulating materials shall be used.

(4) A ¾-in. flash-over dimension must be maintained.

(5) The ignition cables, wherever possible, must be inside one metal shield.

(6) Magneto shields must be watertight and easily removable.

(7) Ignition cables must be enclosed in a metallic cover of good shielding-material, providing protection for the individual leads against oil, gasoline and water, and must assure positive protection against mechanical abrasion.

(8) The type of construction must be such as to permit flexibility of application to different types of aircraft engine.

(9) Low-resistance connections between the members of the shielding system are essential.

(10) The shielding of spark-plugs must satisfy the following requirements; they
  (*a*) Must not interfere with cooling of plug or engine
  (*b*) Must provide for reasonably easy installation and servicing of the plug
  (*c*) Must be protected against short-circuit caused by rain; and
  (*d*) The spark-plug shield must make good electrical connection with the engine block.

This tentative specification also covers suggested tests for shielding, spark-over, insulation resistance and corona.

Spark-Plug and Wiring Shielding

The B. G. Corp. has made several experimental shielded plugs of which two may be mentioned. The angle type, which has bakelite insulation in the elbow, is shown at the left in Fig. 7; the new type all-mica plug is shown at the right and is a modification of the first straight type. Both of the earlier types performed reasonably well in service, but each had disadvantages. No shielded spark-plug has been generally accepted as ideal under all conditions.

In view of the foregoing situation and also because of the necessity for plug shielding, the Aircraft Radio Corp. designed a shield for a standard plug as shown in Fig. 8. This is now being manufactured by the American Bosch Magneto Corp. At first it was thought necessary to provide maximum ventilation for cooling the plug. Louvers and holes were used freely after an extensive study had determined their location and dimensions. On actual engine-tests it was found that a standard plug ran cooler with the shields than without; also that an open plug was more easily fouled than one fitted with the shield. These test results have been substantiated in other engine laboratories.

While no argument is advanced against those who may say that this type of shield has disadvantages, it is claimed that it is a reliable and practical solution at least until the advent of a satisfactory shielded plug, or other spark-plug shielding.

In considering the future design of shielded spark-plugs, the type of terminal should be settled upon immediately. It is a part of the plug and, as such, should be made and sold by the spark-plug manufacturer. There have come to our attention eight designs of shielded plugs each having a terminal—applied to the wire—that is not interchangeable with any other. Perhaps this is a fit subject for the Standards Committee of the Society. It is of the utmost importance to have at least a tentative standard shielded spark-plug terminal to grow up to.

There are two general types, rigid and flexible, of shields for the electric conductors. By the rigid type is meant those shown on the Wright J-5, Fig. 2; the

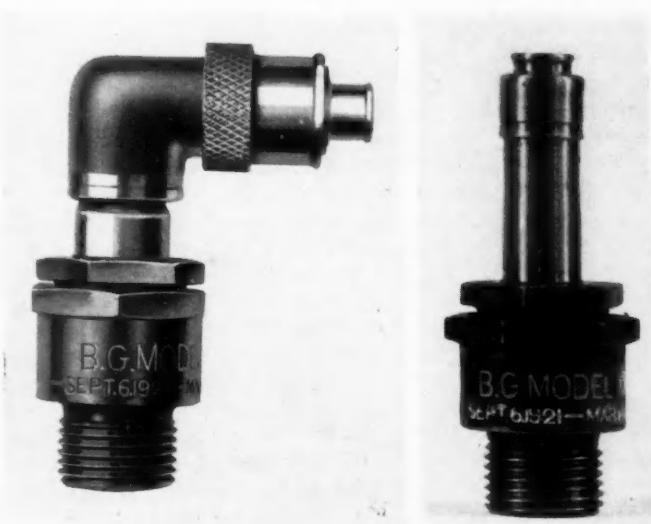


FIG. 7—TYPES OF SPARK-PLUG SHIELDING

The Angle Type Which Has Bakelite Insulation in the Elbow Is Shown at the Left. The New Type All-Mica Plug, Which Is a Modification of the First Straight Type, Is Shown at the Right

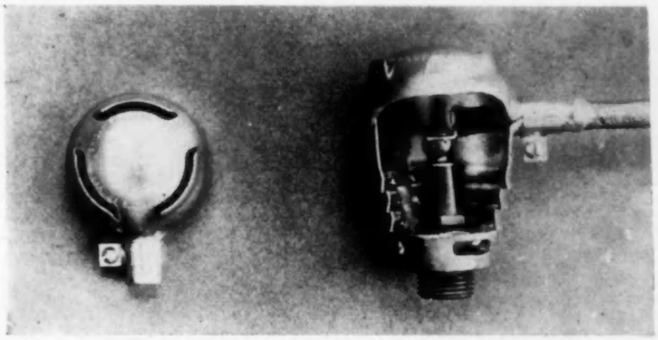


FIG. 8—SHIELD FOR A STANDARD SPARK-PLUG

Breeze manifold; and the Universal design, Fig. 5. These types are a natural evolution from the unshielded-wire manifold. Its shielding qualities are excellent and, when carefully installed, it gives good mechanical protection to the wires as well as reasonable resistance to oil, gasoline and water.

The flexible type of wire shielding was first used in service in England during 1917. This consisted of the regular spark-plug cable over which was applied spirally a wrap of varnished cambric and, over-all, a close-woven-copper braid. The wires were individually in the open between magnetos and plugs, no manifold or conduit being used. Provided this was bonded to the engine every 10 in. or so, it provided excellent shielding insofar as the wiring was concerned. As to possible mechanical injury and exposure of the rubber insulation to oil and gasoline, it left much to be desired.

The next definite step in the development of flexible shielding for the cables was taken by the engineering division of the Army Air Corps at Wright Field. It caused a wiring harness to be made up that had no rigid conduit but, after being taped, a metal braid was woven over the whole assembly. While this experiment was not successful it did serve as an incentive toward the development of the Rome Wire Co. molded harness. This company had for years been making power cables for portable machinery by enclosing the conductors in a molded-rubber jacket of extreme toughness. It was thought that, if the wires in an engine harness could be enclosed in a similar molded jacket, it would give excellent protection to the insulation on the high-tension conductors. Given a good mechanical structure, the necessary shielding could be added.

It will be noted in this development that reliability and not shielding has been given first consideration. It is felt that reliable ignition-performance is to a large extent dependent on maintaining the perfect insulation of the wires. In any design of shielding whereby the wires are drawn into a conduit they are, comparatively, more liable to injury than where they are sealed in a protective jacket at the manufacturer's plant. Further, there is less possibility for gasoline and oil to enter and remain in contact with the insulation. It is believed an advantage to have a flexible-wiring harness; it is more easily mounted and dismounted, especially when the engine is in the plane.

The Rome molded ignition manifold is made in four sections, giving such advantages as easier mounting, neater appearance, less weight and cost. With shielding or without, the engine manufacturer should be able to purchase a complete wiring-harness, requiring no

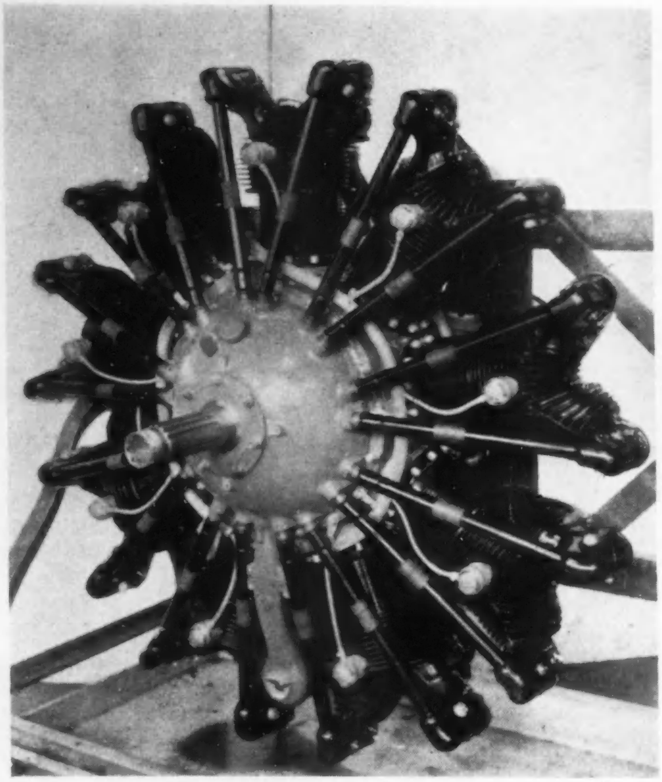


FIG. 9—WASP ENGINE EQUIPPED WITH ROME SHIELDED-MANIFOLDS

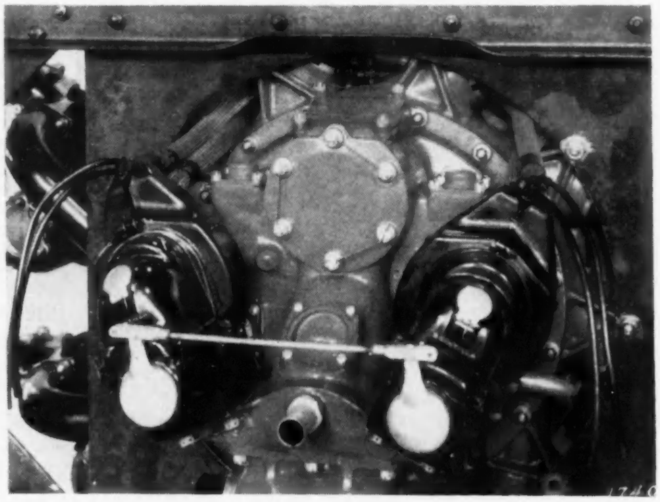


FIG. 10—REAR VIEW OF THE ENGINE SHOWN IN FIG. 9
The Shielded Magnetos of the Double-Outlet Type, Which Are Applied for Use with This Type of Manifold, Should be Noted

work other than mounting, in much the same manner as he obtains other accessories such as plugs, magnetos, carburetors and the like.

The criticism has been made that woven shielding is more susceptible to injury than a solid or flexible tube. It is. However, compared to the loose type of braid, there are many advantages in having the shielding tightly woven on a resilient molded-assembly. As the tensile strength of the wire used in the braid is about twice that of copper, only reasonable care is necessary in service to prevent injury. This seems to be proved by the service records available to date. At least it can be said that the spark-plug cables are protected as in no other design.

Fig. 9 is a view of a Wasp engine equipped with Rome shielded-manifolds. Fig. 10 is a rear view of the same engine, showing the shielded Scintilla magnetos of the double-outlet type which are supplied for use with these manifolds.

In conclusion, it is the opinion of the authors that ignition-shielding is justified by at least two results already attained under service conditions with equipment of modern design:

(1) More reliable ignition performance produced by mechanical protection of magnetos, cables and spark-plugs
(2) Greatly increased range and scope of radio operations

THE DISCUSSION

M. M. EELLS[3]:—Based on my experience with aircraft radio, I venture the opinion that most of the applications of radio to airplanes will be simply the installation of long-wave receiving-equipment. Shielding is necessary for the engine; but, in such a discussion as this, I want to be certain that the following point is not lost sight of.

There are two degrees of shielding; one that is sufficient, practically, for long-wave reception, and a more airtight system of shielding that is necessary where short-wave reception will have to be accomplished on the airplane. This remark is based upon the system we have evolved for our more than 40 mail planes that have been flying regularly with the aid of radio for almost a year.

It is not my intention to becloud the issue. I simply wish to emphasize that it is not necessary to pay for the initial cost or the subsequent maintenance of shielding sufficient for 50 m. (164 ft.) when all receiving will be done in the neighborhood of 1000 m. (3280 ft.). One detail that might be mentioned is the fact that, for our conditions, shielding is not necessary around the rear plugs of our air-cooled engines, a practice which I would hardly recommend were our planes to carry receiving equipment for short waves.

HERBERT HOOVER, JR.[4]:—The shielding mentioned by Mr. Robertson is fine from an electrical viewpoint, but I do not believe that shielding at present will stand up under the continuous grind of transport operation. I do not believe that it is likely to develop for some time to come; rather, I think it will be evolved slowly. Engines did not develop into their present status in a day; they were evolved gradually over a period of years. The development of shielding is likely to be similar, particularly in regard to spark-plugs.

One of the present difficulties is the lack of standard connections between spark-plugs and harnesses; none

[3] Manager of communications, National Air Transport, Inc., Chicago.
[4] Communication engineer, Western Air Express, Los Angeles.

of the different types are interchangeable. Many points in these systems of shielding, illustrated by Mr. Robertson, are good in themselves. Eventually one will be evolved that will be a combination of all their good points. In the last six months tremendous strides have been taken in shielding developments, and we expect to see even greater improvement in the coming six months.

Air Lines Not Experimental Laboratories

F. D. WEBSTER[5]:—The air-transport operators are confronted with a serious situation in that the engine manufacturers are regarding the air-transport operators who carry passengers and mail as constituting experimental laboratories. They seem to expect the operators to equip the engines with shielding, fly them, and then have the operators tell them what results they get. That is not the operators' problem; it is the engine manufacturers' problem. I wish to enter my protest against such practice.

CHAIRMAN PAUL GOLDSBOROUGH[6]:—We found that a somewhat similar situation existed, but we felt that it was not desirable to wait until the device was perfected and therefore attempted to come as nearly to the ideal as possible. In connection with the service life of the harness, we have used a Universal development for some months on our Chicago-Cleveland division. We think that the harness, exclusive of the plug shield, will perform satisfactorily for the length of time that we have allotted to engine overhaul, which runs around 300 hr.

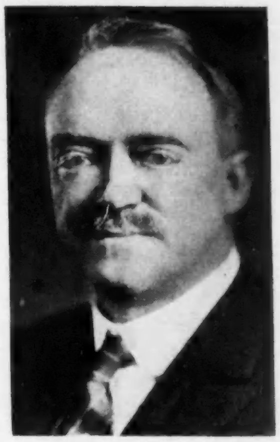
A. RAY BROOKS[7]:—If the engine manufacturers go into this problem they should not stop short of the end. The radio is reaching a stage of development which must include it as a means of safety in all air operation. Recently, a number of very serious crashes have occurred that might have been avoided if the airplane had been equipped with receiving or two-way radio-apparatus. If we are to have the engine manufacturers install proper shielding and the airplane manufacturers bond the airplane properly from the airplane purchasers' and the operators' viewpoints, this ought to be done completely and effectively at the source. Difference in cost between half and whole measures is not important. We have acquired many data in the last year concerning this shielding problem, and our experience indicates that complete shielding is desirable from all viewpoints.

PAUL GOLDSBOROUGH

MR. HOOVER:—A great difference exists between the types of service that shielding is to perform in the actual flying of an airplane. One type of shielding may be very suitable to an individual flyer or a private owner if it is electrically perfect. But to a transport company which flies its planes an average of 3 to 6 hr. per day and considers all types of service requirements, that particular type of shielding might be absolutely out of the question. Such companies may desire to apply another type of shielding, which perhaps has no greater initial cost but which is better adapted to their service features. It is not necessarily true that all shielding falls into the same categories of use.

Horizontal versus Vertical Antennas

C. FRANCIS JENKINS[8]:—In experimenting with a four-place cabin airplane equipped with a J-5 nine-cylinder engine which was unshielded, we intended to obtain data concerning the broadcasting of television on a low-power short wave-length as we flew along and to rebroadcast it from a station located about 5 miles north of the City of Washington. We did not believe that the radio problem was the engine builder's problem. It seemed to us that it was the radio man's problem to maintain communications without calling upon the engine man for help. We tried to work out our problem alone.



C. F. JENKINS

The first effort we made was to go aloft with a wire coiled up in the hand of the radio operator, and I tied my handkerchief to the end of the antenna. After we had the plane in the air, the radio operator threw about 120 ft. of wire overboard. We had no interference whatever in the reception of voice transmission sent from our station about 35 miles distant. At a later date, we built a transmitter and receiver and all the power required was taken from dry-cell batteries.

We flew to New York Harbor and back to Washington keeping in constant two-way communication with this outfit—consisting of batteries, transmitter and receiver, which weighed 26 lb.—the whole operation being performed in accordance with a theory that the firewall in the airplane created a natural shield from the engine to the antenna that was flying aft of the plane. In other words, that firewall created an electrical shadow behind the plane; therefore, if the antenna flew in that electrical shadow there should be no interference. We afterward improved this performance to some extent.

Engine Builder Not To Solve Problem

I do not believe that the engine builder should be charged with the task of the radio man. If the radio man is not smart enough to make his radio work, it is his job and not the job of the engine man. We use a horizontal antenna simply because we have never flown a vertical one, and there are hundreds of thousands of horizontal antenna that perform daily all over the United States. I see no reason that we should suppose the difficulty in the plane would be any different from the difficulty at a land station. I believe there is no occasion whatever for asking assistance from the engine man in two-way radio communication from a plane to the ground.

[5] Communication engineer, Colonial Airways Corp., New York City.

[6] Vice-president, Aeronautical Radio, Inc., City of Washington.

[7] In charge of air operations, Bell Telephone Laboratories, Inc., New York City.

[8] Jenkins Laboratories, City of Washington.

CHAIRMAN GOLDSBOROUGH:—Did I understand you to say that in your receiver test you used a trailing antenna?

MR. JENKINS:—The word "trailing" means nothing very definite. We are using an antenna which flies straight back, aft of the plane, and not having a lead weight on it in the sense of trailing. We use a small "wind-sock" which helps to carry the antenna. We flew from Hoover Field to Philadelphia and back again without the wind-sock one day and maintained perfect two-way communication. We looked back and could see that the antenna wire had sagged somewhat, but it did not drop below the electrical shadow of the firewall.

CHAIRMAN GOLDSBOROUGH:—In defense of the radio manufacturers, at a meeting in Washington in March, 1929, when the technical committee of the radio-transport operators met with the manufacturers, they were asked to design their equipment to work on non-trailing types of antenna, because certain flying conditions made a fixed antenna necessary.

A. W. PARKES, JR.[9]:—What sort of receiving set was used on these tests, and what sensitivity did it have?

MR. JENKINS:—It was a receiver we made, in which part of the transmitter was used for amplifying so as to reduce weight, and has a "gain" of about 25,000. We were trying to maintain two-way communication over considerable distances, but we have not flown over a distance of more than 200 miles and I cannot speak from experience for distances greater than that.

[9] Radio engineer, Aircraft Radio Corp., Boonton, N. J.

[10] Engineer, Breeze Corp., Inc., Newark, N. J.

Mast Antennas Mentioned

MR. HOOVER:—The history of the mast antenna originated at the Bureau of Standards in its development of the radio beacon. In the experiments the Bureau found extremely large errors when using a trailing antenna —sometimes during the day, but particularly at night— where the experimenter could not get the signals or the bearing on the beacon. It was found that a non-directional antenna was needed; that is, an antenna which would pick up equally in all directions. The vertical antenna was the only type that performed satisfactorily. The height of the vertical antenna from the plane was of course limited to about 6 ft., due to practical conditions. It was necessary to develop a receiver with a gain which would give the necessary signal strength on that antenna. It was for this reason that the high-gain receiver was first adopted.

F. G. GARDNER[10]:—One of the concrete things that faces us as manufacturers of shielding is the fact that there seems to be no uniformity of terminals. We have to manufacture some 12 or 14 different types of terminals and adapters for shielding spark-plugs. I think that the Standards Committee should attempt uniformity of terminals.

Wind Resistance of Automobiles

(*Concluded from page* 14)

two principal dimensions will show that the length of the body, back of the hood, of course, in the sketch at the right is only 2.8 times the height of the body.

I accept most appreciatively President Warner's information, entirely unknown to me, that the principle of aerodynamic reflection was used by Professor Ober of the Massachusetts Institute of Technology eight years prior to Professor Prandtl of Göttingen University. This then establishes American priority of this discovery. In correcting this oversight on my part, in this place, I wish to remark, however, that in referring to the Göttingen tests I used the qualification "very likely."

Imperfections of Wind-Tunnel Method

Regarding the imperfection of the reflection method for reproduction of ground effect in wind-tunnel tests of automobiles, I agree with President Warner that an automobile moving along the surface of the highways entraps a certain volume of air underneath the chassis and drags it along, so to speak, over the road. This dragged-along volume of air is nothing other than the so-called boundary layer, which grows in thickness gradually, from zero at the front to the maximum at the rear of the body, equal to about one-fortieth of the length of the body, according to measurements made on hulls of dirigibles. Therefore it very likely never reaches the ground, as at the usual lengths of car this dimension will be approximately 3 in. This would be true if the bottom surface of the car were comparatively smooth which, as we very well know, is not the case, since the front axle, cross-members of the chassis and other parts will disturb and complicate the formation of a typical boundary layer. In the wind-tunnel models of the cars all these details should be, therefore, reproduced to obtain a similar disturbance of the flow, and the scale-effect correction should then take care of the lack of geometric similarity of the flow around the model and the full-size car. I feel, also, that this is not the whole story, but to go farther into this question would be beyond the scope of this discussion. I therefore conclude, with President Warner, that this is admittedly the best method we know of for measuring the resistance of a model, but it is not ideal.

I agree also with President Warner that the usual wind-tunnel test will correspond to a case of a car driven with no wind, but I would add also with direct head wind or tail wind. A side wind may produce very marked changes in the flow of air around the car and the resulting air resistance; however, this can be accounted for also by testing the models at different angles of yaw. Having this in mind, I explicitly advised, in the paper, a more extensive study of the effect of lateral winds before some radical departures from the present designs are decided upon.

I cannot agree with President Warner as to not applying the same conclusions with some reservations to the case of Sir Henry Segrave's racing car. The 20 per cent saving in resistance does not apply to the total drag but to the induced-drag item only. Granted that irregularity of the ground, while modifying the flow of air, cannot be reproduced in a wind-tunnel test, such cars are never driven on bumpy roads; furthermore, raising the ends of the chassis cover would reduce its lifting ability and prevent it still more effectively from becoming an airplane. The same applies to fast passenger-cars, as they are driven fast only on smooth roads.

The Wind-Tunnel as an Engineering Instrument

By Dr. A. L. Klein[1]

Los Angeles Aeronautic Meeting Paper

Some of the ways in which wind-tunnels can be used to provide data that will serve as a guide to the designing engineer are pointed out by the author. Among these are tests of the lift, drag, center-of-pressure travel, the interference of wings and fuselage, effect of interference drag of minor parts and the statical and dynamical stability.

A need is said to have arisen for some form of interference-drag device for increasing the drag of very high-speed airplanes to enable them to be landed in smaller fields.

The discussion, in the main, is on the subject of wind-tunnel construction and operation and the need for having small motors to reproduce the conditions in actual airplanes. The relative costs of atmospheric and high-pressure tunnels are compared.

Of the many problems that arise in the design of an airplane, those in connection with the wings can be most easily investigated in the wind-tunnel. The determination of the mean aerodynamic chord of an unorthodox wing cellule is one of the most obvious types of wind-tunnel problems. It is highly desirable that the wing cellule of the airplane be investigated independently, as only by determining the polars of the wing cellule alone and then repeating the measurements with the fuselage, nacelles and other parts in place, can the interference between them be measured. By following this procedure and then trying different types of filleting, marked improvements in the characteristics of the complete airplane can be obtained. Muttray has shown that an improperly filleted fuselage can have a marked effect upon the wing-fuselage interference[2]. A badly designed fuselage and fillets cause a great decrease in the equivalent span of the airplane. The interference drag can be almost completely eliminated by correct design. It is well known that anything attached to the upper surface of a wing has a very detrimental effect. If proturbances cannot be avoided, a model of sufficient scale should be constructed and their design worked over so that they will have the least effect. All re-entrant angles and small gaps, especially up above the wing, should be avoided. The recent work of the National Advisory Committee for Aeronautics has shown that a properly mounted wing-engine has only one-sixth the drag of the present normal type of engine nacelle[3].

Miscellaneous Drag Problems

The present type of landing-gear has very large drag, principally because of acute angles between the struts. Landing-gears can be tested at full scale in a large wind-tunnel or at half scale in a smaller wind-tunnel. The N.A.C.A., in its brilliant development of the venturi cowling, has pointed the way for a more scientific attack upon drag. The British towend ring, though different in principle from the N.A.C.A. cowl, produces similar results.

A newer type of drag problem has arisen in connection with very high-speed airplanes. This type of plane is necessarily so clean that its gliding angle is very flat. This characteristic, combined with the tendency toward low-wing monoplanes, has produced airplanes having great floating tendencies. These planes are very difficult to land in small fields over obstructions. There are three possible methods of landing them, all unsatisfactory: (*a*) The pilot may glide into the field steeply, picking up speed all the time and then floating a long distance before making contact; (*b*) he may glide in at his minimum gliding-speed and touch the ground at approximately the same distance from the obstruction as before; or (*c*) use the last method which is to squash into the field and pull out just before contact, thus making a short landing.

The first two methods are impossible in small fields, while the last method requires great skill and is very dangerous in bumpy air. Side-slipping a high-speed airplane is not very effective, as the fuselage used in this type is a very good streamline body at any ordinary angle of yaw. A few calculations will show that enough flat-plate area to decrease the lift-drag ratio to a reasonable value will be almost impossible to obtain in a safe and controllable manner. The usual form of spoiler is likewise inadvisable as it decreases the lift markedly, thus increasing the sinking speed. The only reasonably safe way to decrease the lift-drag ratio is to use some form of interference-drag device that will not spoil the lift and yet will produce a large increase in drag. This is an ideal wind-tunnel problem, and the polar and pitching-moment curves of any contemplated device can be easily determined.

High-lift devices should always be investigated to determine their effectiveness. Enough tests have been made with models and with the corresponding full-

[1] Assistant professor of aerodynamics, California Institute of Technology, Pasadena, Calif.

[2] See National Advisory Committee for Aeronautics Technical Memorandum No. 517.

[3] See National Advisory Committee for Aeronautics Technical Note No. 320.

scale airplane to prove the reliability of the wind-tunnel methods.

Dynamical Stability Difficult To Test

All of the foregoing tests can be made with the ordinary three-component wind-tunnel balance. To investigate the complete airplane with its six degrees of freedom, a six-cylinder balance is necessary. The model of the complete airplane can be tested for stability and control, the effectiveness of the controls measured and the statical stability investigated. The problem of stability, power on, is more difficult. The statical stability of the airplane can be determined without the slipstream, and after the coefficients have been determined the moments of the gravity forces and the propeller thrust can be added in. To work with the slipstream a small high-speed motor is necessary. To date no satisfactory power unit has been developed, although a number of laboratories have designed or purchased apparatus for this purpose.

The study of dynamical stability is very difficult, as it requires an entirely different type of set-up than any of the foregoing tests. The model must be free to oscillate and it must be dynamically as well as geometrically similar to the full-scale airplane to be investigated.

The problem of wing or tail flutter is very difficult to investigate, as the model must be constructed so as to have the same geometrical shape, structural rigidities and mass distribution as the airplane. Work of this nature has been done and more will be done in the future. The surface texture of airfoils is now being worked on in the world's laboratories, and definite data on the effect of corrugations, rivet heads and the like will be available in the near future.

It is well to mention that propellers are being constantly tested in the laboratories that specialize in this work and our present remarkably high propeller efficiency has been achieved as a result of their efforts.

The writer does not believe that all of the tests mentioned are necessary for the design of a conventional airplane, but every plane should have its polars, moment curves and static stability determined. The rules now extant for dynamic stability give satisfactory results and those for the prevention of dangerous spinning characteristics are sufficient for the designer in most cases.

THE DISCUSSION

CHAIRMAN L. M. GRIFFITH[4]:—The wind-tunnel is more or less of a mystery to many who are otherwise well versed in aeronautics. I have personally had some experience with it, and it is still a mystery to me. One thinks the building of a tunnel is a simple sort of job. He sees a tunnel running, notes its character, gets the dimensions and drawings and builds one like it. If he has had no experience, he says, "In two months we will have the tunnel finished and start making tests." But after the tunnel is completed in the two months, usually a year or two years is required to find out whether it is a good tunnel or not. There seem to be many things to contend with when one deals with air at high velocity through a wind-tunnel; the air does not follow the nice, smooth lines that were laid down on the drawing-board. Information resulting from wind-tunnel tests of all kinds, however, forms the real basis of our aerodynamic advance. We discover many things with full-size machines but cannot very conveniently measure them. The quantities involved cannot be determined readily, as we found at Langley Field; therefore we are dependent for much of our information upon the results of tests in wind-tunnels on models and parts of airplanes.

DR. A. L. KLEIN:—I can echo what Mr. Griffith has said, since, after the tunnel at the Institute was built, we found that one place inside of its perfectly conical body the air was moving upstream. We were much astounded; then we did a few things and got the air to go in the same direction over all of the tunnel.

Full-Scale Application of Tunnel Results

CHAIRMAN GRIFFITH:—Many airplane designers who have had a little experience are prone to think that the wind-tunnel is suitable only for the use of research men working on problems that have no bearing on the actual airplane. On the other hand, there may be one or two designers who have implicit faith in any result that comes from a wind-tunnel. Somewhere between these two views is a happy medium where the work of the designer is guided, not controlled, by wind-tunnel results. All such results are subject to interpretation and modification as necessary to suit the actual full-scale design, taking into consideration the difference in operating conditions between the flight of the full-size airplane and the passage of air around the small model in the wind-tunnel.

STANLEY H. EVANS[5]:—What model airscrew speed can you get in the tunnel, Dr. Klein?

DR. KLEIN:—Our largest models will be of 6-ft. span, and an airscrew of the same proportional size as that used in an airplane would be approximately 18 in. in diameter. To run that propeller at the same $V/_nD$ ratio as the actual propeller would require a speed of 10,000 to 15,000 r.p.m. Great difficulties have been experienced with the small electric motors at such speeds because of overheating. We hope soon to have a high-frequency generator to drive a three-phase motor at any speed up to 20,000 or 25,000 r.p.m. and to be able to control its speed by controlling the speed of the motor generator. Such apparatus is very expensive, and the sets built to date have not been very satisfactory.

MR. EVANS:—I assume you could use a much larger propeller and only a small portion of the airplane model.

DR. KLEIN:—That could be done, but we were thinking of running the propeller in the stability tests of the airplane as a whole. If you were developing nacelles, you could make a model of just the parts of the structure adjacent and use a larger propeller; this would require more horsepower. The only successful work of this type has been done in England and Germany, and one of the aerodynamical laboratories in this Country received a duplicate of one of these motors and found that it ran red hot.

[4] M.S.A.E.—Vice-president, general manager, Emsco Aero Engine Co., Los Angeles.

[5] Aeronautic engineer, design staff, the Douglas Co., Santa Monica, Calif.

Trouble with High-Speed Electric Motors

WELLWOOD E. BEALL[6]:—The motor to which Dr. Klein refers was imported from Germany by Prof. Alexander Klemin, of New York University. It was about 2½ in. in diameter and about 9 in. long. It operated on 500 cycles and required a special converter, also of German manufacture. This small motor developed, as I recall, about 1¾ hp. and was similar to one the Navy experimented with some time ago.

This motor was intended to be mounted in a wind-tunnel model and drive a propeller so that conditions approximating actual powered flight could be simulated. It was designed for operation at 40,000 r.p.m. with the propeller geared down to a suitable speed. However, operation at this speed was found to be impracticable, due to the motor overheating. It was then adjusted to turn at 36,000 r.p.m. With the motor mounted by itself in the laboratory and when it was turning a small propeller which threw considerable air upon it, this speed proved to be practicable. However, as soon as it was mounted inside a model for test, where no air current could strike it, it immediately became hot and after 45 sec. of running became too hot to operate.

The propeller reduction-gears were mounted on the motor in such a way that the torque reaction, and consequently the power delivered to the propeller, could be measured. This reduction-gear train was carried by a frame that pivoted in such a way that the torque reaction tended to rotate it. This rotation was restrained by a calibrated spring and the torque was indicated by a long, thin arm. This torque indicator operated satisfactorily in still air but, when placed in the slipstream of the propeller or in the wind-tunnel, it became inoperative due to the impact of the wind on it. This prevented the indication of the torque and consequently the calculation of the power.

This motor was also equipped with a revolution counter consisting of a worm-gear train and a small disc about an inch in diameter with one mark on its circumference. To obtain the speed of the motor, it was necessary to watch this disc, count its revolutions and calculate the result. This method is suitable for obtaining the speed of the motor before it is mounted in the model but very inconvenient when mounted in the model and in the tunnel. The reasons for this are obvious.

Although this motor was rather disappointing, it did arouse considerable interest and at least has provided a start in obtaining data for predicting the effect of the propeller slipstream and wash by means of wind-tunnel tests. The motor, I believe, has been sent back to its manufacturers to be rewound and rebuilt to operate at lower temperatures under load. A new system of distance-type indicating devices for the speed and torque is also being devised. With this rebuilt motor it is hoped that many valuable data may be obtained.

CHAIRMAN GRIFFITH:—The difficulty of running small-motor tests in the wind-tunnel is one of the factors that led to the present large tunnel at Langley Field and is leading the National Advisory Committee for Aeronautics to plan the construction of a much larger tunnel. I understood that the size of this was to be in the neighborhood of 30 ft. high and 40 ft. wide, but Dr. Klein tells me it has been increased to 30 x 60 ft. It is interesting to note that the 20-ft. tunnel takes about 2000 hp. to drive it.

With reference to Dr. Klein's comment about the detrimental effect of protuberances on top of the wing, I have been curious to know how much the Dornier-X speed might be below that of a similar airplane having the engines mounted within the wing itself.

DR. KLEIN:—German engineers have made some tests but the results have not been completely published. They showed that locating the propeller completely above the wing does not interfere with the wing. Before he built the flying-ship, Dr. Dornier expected to get a considerable increase in lift at take-off, because the slipstream would be entirely above the wing and increase the circulation about the wing.

QUESTION:—Has any work been done on an airplane which has some variable-drag device to increase the drag on landing so as to reduce the landing speed?

DR. KLEIN:—I do not know of any that has been done. We expect to try several devices of our own and of other people for this purpose. I think personally that the only feasible means is to use some interference-drag device; any other way is open to objections on the ground of reduction of controlability.

Variable-Density Wind-Tunnels

QUESTION:—What is the situation in regard to increasing the air density, using a closed pressure-system?

DR. KLEIN:—That is one way of achieving a large Reynold's number, which is our criterion of scale effect. A tunnel 5 ft. in diameter that can be pumped up to 20 atmospheres has been built at Langley Field and has been very successful. The British are contemplating building a similar tunnel. The Langley Field tunnel was exceedingly expensive. I imagine a high-pressure tunnel would cost about five times as much as an open tunnel of the same size. Our tunnel has a 10-ft. diameter, and we get an increased scale-factor by running at air-speeds up to 200 m.p.h. I think that our tunnel, without the building, cost approximately $75,000. We did not expect to get such high speeds but are pleased that we can get them. We build wind-tunnels and get astonishing results; nobody has very clear-cut ideas as to what the ideal wind-tunnel is.

CHAIRMAN GRIFFITH:—An interesting item about the variable-density wind-tunnel at Langley Field is the tank in which the tunnel was placed. It was a very good piece of ship-plate work. The shell is 15 ft. in diameter and about 30 ft. long, with hemispherical ends, and weighs 43 tons. The side plates are 1¼ in. thick. This tank was tested to a pressure of 450 lb. per sq. in. and showed very little leakage. It cost $24,000, and $1,200 more was spent to get it from the place where it was built to the site of the tunnel. When we got it there, we began to figure how much more money we would have to spend. We had enough to put up a building and, through the cooperation of the Navy Department, used Navy equipment that originally cost about $80,000 and had been used in the helium plant at Fort Worth, Texas. Consequently we were able to do a relatively big job for a small sum of money.

Plans for Huge Tunnel at Langley Field

A MEMBER:—Is that very large tunnel at Langley Field actually being constructed and is it possible to

[6] Jun. S.A.E.—Assistant chief engineer, Walter M. Murphy Co., Pasadena, Calif.

make a guess as to the power that will be required?

DR. KLEIN:—I believe that the National Advisory Committee for Aeronautics obtained from the Congress an appropriation of $900,000 for it and expects to use about 8000 hp. The Committee was considering the larger tunnel very seriously and was debating how to build it.

CHAIRMAN GRIFFITH:—This wind-tunnel problem is really very interesting. When we built the 5-ft. variable-density tunnel at Langley Field we thought we would be in an excellent position to investigate all kinds of aerodynamic problems in the tunnel. Shortly after that tunnel was finished, we started the 20-ft. tunnel with the idea that we would then be able to make tests at the same Reynolds number but with different aid densities and model scales. The interior of the high-pressure tunnel burned out several times and we found that wood was not a suitable material at 20 atmospheres, or a pressure of about 300 lb. per in., as combustion is extremely energetic at that pressure and air velocity.

All this time the Committee was carrying on full-scale work with airplanes with about 17 different varieties of recording instrument and found the limitations of that method. Having completed the 20-ft. tunnel, it is now building one 30 x 60 ft. To the industry the world over it looks as if it were going to be worth a lot of money. I really believe that, with proper coordination between full-flight tests with all the instruments that can be crowded into the cockpit, tests of the model airplane in a variable-density tunnel and tests in an ordinary tunnel, we can produce a mass of coordinated data that will tie up rather closely the various testing means.

In any case we can look forward to the increasing use of the wind-tunnel and to its influence being reflected in greater aerodynamic efficiency of aircraft. That is very definite. We know that the wind-tunnel has given us the basis on which we have built most of our aerodynamic progress and is going to be the main instrument for further development. It never will take the place of free-flight development, but it is coming closer to it. It is only a question of time, I think, when we shall be able to design aircraft upon the basis of tunnel tests and not miss the computed performance on the full-scale machine by more than 2 or 3 per cent.

GERALD VULTEE[7]:—The result of my experience in flying airplanes is that, if one sometimes could be sure of hitting within 25 per cent of calculations, he would feel much better.

Present Landing-Speeds Seem Safe

JOHN K. NORTHROP[8]:—Will the new landing rules of the Department of Commerce necessitate the use of variable-lift devices, or will it be possible to bring a full-scale machine to a landing much slower than the theoretical figures would indicate?

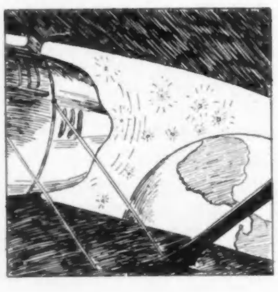
MR. VULTEE:—As I remember the rule, unless the theoretical landing-speed was below 60 m.p.h., the Department required special flight-tests to prove the practicability of the design. If those were passed, and they were not particularly stringent tests, the design was approved. However, I believe, from the experience we have had, that the plane can be brought in at a considerably lower speed than would appear from theoretical considerations.

It is natural to assume that most manufacturers' performance figures on landing-speeds are somewhat optimistic; checking the maximum lift-coefficients of existing commercial planes against the performance that is claimed for them, the maximum lift-coefficients are found to run in the neighborhood of 0.0040 or higher. These are rather high figures. We encountered something similar to that in trying to reduce the landing-speed we had. We found we could not get any assurance of being able to reduce the landing-speed appreciably with any normal wing-section, as by actual flight-tests we already had a maximum lift-coefficient of about 0.0040. However, I believe that a good pilot can bring a plane in rather more slowly than the theoretical figures indicate.

Perhaps we have become used to seeing planes coming in at 60 and 65 m.p.h. and it looks like 45. The landing-speeds we are using now seem to be satisfactory as regards safety. The planes get in and out of fairly small fields and do not average a large percentage of crack-ups on landing; therefore, as an increase in landing-speed will make possible a greater increase in high speed, it seems that we should go a little slowly in drawing conclusions regarding specifying slower landing-speeds. Planes designed for a landing-speed of about 40 m.p.h. would look rather queer compared with the planes that are being built at present. All the builders, I believe, are making a little increase in the allowable landing-speed in their designs, except for airplanes that are built for special purposes, such as training, for which a lower landing-speed is absolutely necessary.

[7] Chief engineer, Lockheed Aircraft Co., Burbank, Calif.; now, with Detroit Aircraft Corp., Detroit.

[8] Vice-president and chief engineer, Northrup Aircraft Corp., Burbank, Calif.



Casting Cylinders in Green Sand

Discussion of D. J. Campbell's Annual Meeting Paper[1]

CYLINDER-BLOCKS, with their hollow form and complicated arrangement of water-jackets, valve passages, pockets and bearings, are difficult to cast, and require a large quantity of cores. These have generally been baked or dry-sand cores, but the author's organization has met with success in making the more bulky cores, those for the cylinder-barrels and crankcase, in green sand. Descriptions and copious photographs and drawings are given of two methods of molding one six-cylinder block in green sand, and the possibilities of the system are indicated by illustrations of cylinders and details of cylinders that have been molded or that are suitable for molding with the cores for the bores and the crankcase formed in green sand.

Cooperation between designer and foundryman is essential in realizing the economy possible with this method of molding, a large part of which results from the great saving in cost of sand. Core-room and foundry layouts are given, also a comparative analysis of the cost of cores, made as far as practicable by the green-sand method, with the cost of dry-sand cores.

In the absence of Mr. Campbell, this paper was presented by E. W. Beach, who took part in the discussion at the meeting. Mr. Campbell since has contributed to the discussion remarks which have been inserted at appropriate points. Experiences and opinions of Chevrolet engineers were most in evidence in the discussion.

CHAIRMAN L. V. CRAM[2]:—Most of those 2000 cylinder-block castings for the Chevrolet four-cylinder engine, which Mr. Campbell has mentioned in his paper, went over my desk before they went to the machine shop. The metal in them was very fine, but I should hate to estimate how many hours were required for removing the fins at the horizontal parting lines.

D. J. CAMPBELL:—This fault was evident to me on most of these castings. It was corrected later by a change in the pattern and the parting line. Discontinuance of production came before sufficient castings were produced to make the improvement evident at the Chevrolet plant.

CHAIRMAN CRAM:—The experiment was not fully a success, and we discontinued it; partly because Arnold Lens, the head of our foundry in Saginaw, Mich., said that he could give us more value for a dollar.

MR. CAMPBELL:—Orders for production volume were insufficient to warrant our best prices, and no assurance could be offered as to the continuation of the engine in future models.

CHAIRMAN CRAM:—We, in the organization, knew that the four-cylinder engine was so near the end of its life that we did not put as much study as we might have done into its founding; but the cylinder-block of our six-cylinder engine represents literally thousands of hours of intensive cooperative study of the engineering, foundry, and manufacturing divisions. Some changes having a major effect upon the stresses were made to accommodate and simplify the foundry practice. A thorough study was made, two years ago, of the subject of green-sand casting, and it was dropped because we thought the extra $75,000 needed for dry-sand equipment was unimportant in the final cost of castings made at the rate of 5000 per day.

MR. CAMPBELL:—Dry-sand cores, with the additional investment involved, require less skill and effort on the part of any foundry organization.

CHAIRMAN CRAM:—We expect some day to have a foundry big enough to allow us to try out various methods on a manufacturing scale, but we have not yet been able to spend the amount of money that this would require. However, I do not believe that Mr. Campbell's organization has yet achieved either the cost per pound or the cost per cubic inch of cylinder displacement that has been reached at our foundry in Saginaw.

MR. CAMPBELL:—I am very confident that our organization, under similar conditions of production assurance and choice of product, can reduce the cost considerably lower.

Box Sections Advocated

ALEX TAUB[3]:—Molding cylinder-blocks in green sand has a structural advantage that must be given consideration in addition to the economic advantages that are acknowledged. Bearing-support rigidity is a fundamental necessity in a good crankcase structure, and that structure which will give the maximum rigidity per pound of iron will represent also the maximum result per dollar.

Let us consider a three-bearing crankcase. If these bearings are supported by an overhung wall, such as is shown in Fig. 21, it will be necessary to incorporate a series of heavy radial ribs to prevent bearing-support movement. However, if this bearing can be supported by a box section, such as is shown in Fig. 22, we shall have the maximum of rigidity, since the bearing will be supported with the minimum of overhang.

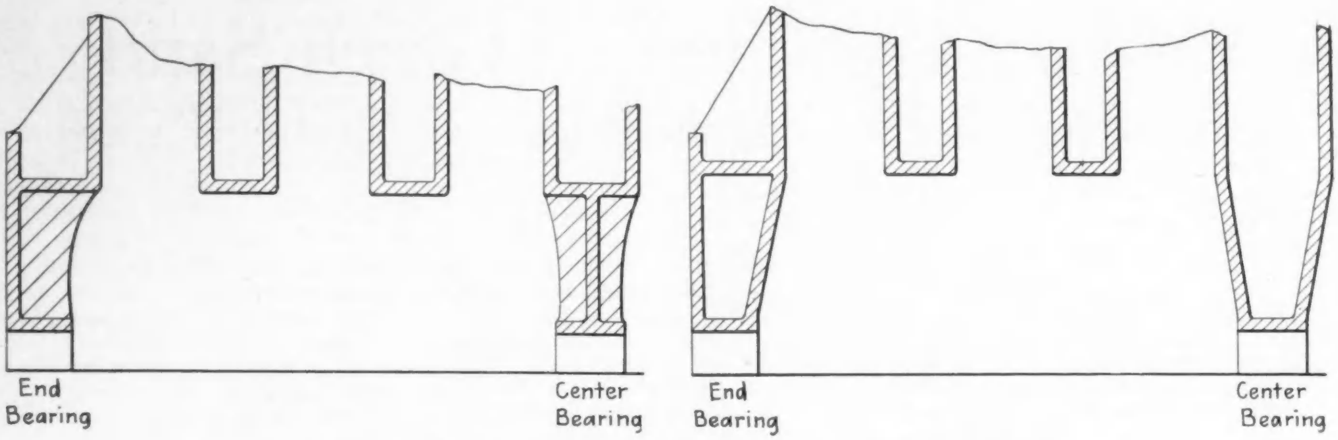
We believe, therefore, that green-sand-molding practice, as incorporated in the Pontiac cylinder-block, should be credited with this improvement in structure, since this construction is natural with this type of molding, the box sections over the bearings being necessary to permit clean withdrawal of the pattern.

Obviously, this box structure can be accomplished by dry-sand coring; but the cost would be increased and

[1] Published in the S.A.E. JOURNAL for February, 1930, p. 177. The author is president of the Campbell, Wyant & Cannon Foundry Co., Muskegon, Mich. The abstract accompanying the paper is reproduced herewith with the addition of a statement about the discussion.

[2] M.S.A.E.—Assistant chief engineer, Chevrolet Motor Co., Detroit.

[3] M.S.A.E.—Development engineer, Chevrolet Motor Co., Detroit.



BEARING SUPPORTS FOR SIX-CYLINDER THREE-BEARING ENGINE

Fig. 21—Overhung Bearings with Ribs

Fig. 22—Bearings Supported by Box Sections

scrap hazards would be enhanced, which facts are probably the underlying reason why the box structure is not in general use, even though structurally advantageous.

MR. CAMPBELL:—Scrap would not be increased by dry-sand cores, which offer greater flexibility to any form of rib construction.

MR. TAUB:—Much more attention will be paid to crankcase structure in the future than in the past, since it is now recognized that structural weakness is what limits the output that can be obtained without roughness.

Mr. Campbell stated that the difference in cost between the dry-sand and green-sand methods for the Pontiac cylinder-block is only 91 cents. I am much surprised, as it was my impression that the difference was greater.

Molding with an Automatic Machine

E. W. BEACH[4]:—Mr. Campbell has been very conservative in his cost figures, because he did not wish to make any statement to which exception might be taken. His figures are based on reclaiming only 75 per cent of the sand used in making the green core and the cost of removing the other 25 per cent as refuse.

During four years while I was with the Ferro Foundry & Machine Co., of Cleveland, Mr. Stoney, who was at that time plant superintendent, conceived the idea of making the Chevrolet cylinder-block in green sand. His method was different from that of Mr. Campbell in that he poured the cylinder in a horizontal position, in a two-part flask. His first operation on the core was on a specially designed machine in which the two halves of the core were made in separate boxes on arbors. The machine automatically rolled or "booked" over, lifted off the top half of the core-box and lifted the core, by the arbor, out of the lower half of the box as a unit, swung it around and lowered it into position in the mold, all automatically. The only dry-sand cores used, as I remember it, were for the water-jacket.

Mr. Stoney's two machines, one having both cope and drag patterns for the mold, and one for the core-making, were of the column type and had four arms and four stations each. They came nearer to making possible an ideal automatic foundry method than anything that has ever been adopted—ideal in method, but impractical in point of maintenance and constant accuracy.

CHAIRMAN CRAM:—During the last six years, we have eliminated about one-quarter of the dry-sand cores used in manufacturing the Chevrolet car. Where we shall stop in this elimination will depend upon the progress the foundry can make in its methods and the ingenuity of the engineering department in developing design.

So far, I believe that we can get better results by the judicious use of dry-sand cores inside the crankcase than with all green sand. This opinion takes into consideration something more than the cost of the castings. Swells, mismatches and crushes occur in the green-sand molds much more often than when dry-sand cores are used. The coarseness of the sand plays an important part in the size and weight of individual castings in green sand.

MR. CAMPBELL:—Our green-sand method does not produce inferior results as concerns swells, mismatches, and crushes; the only difference evident in the Chevrolet castings was a superiority over those produced by the dry-sand method. Mr. Cram must have reference to previous experience or experiences other than on the Chevrolet cylinder-block.

MR. BEACH:—During the three years that the Pontiac cylinders were being cast at the Campbell, Wyant & Cannon foundry, the sand was given hourly tests for moisture and permeability. One boy in the laboratory was continually occupied in making and recording these tests of the material used, as a part of the routine of manufacture, and a portion of his work was charged against that job. Precautions like this are essential in using green sand.

MR. TAUB:—Is it not now possible to reclaim dry-core sand as well as green sand?

CHAIRMAN CRAM:—Core sand that is not too much burned can be reclaimed.

[4] Engineering executive, Campbell, Wyant & Cannon Foundry Co., Muskegon, Mich.

The Properties of Gasolines with Reference to Vapor Lock[1]

By Oscar C. Bridgeman[2] and Elizabeth W. Aldrich[3]

Annual Meeting Paper | *Illustrated with* Charts and Diagrams

VAPOR lock is the interruption of gasoline flow through the fuel-feed system. Its occurrence may either be due to the fuel or to the characteristics of the feed system. The present paper deals with the properties of fuels which determine their tendency to cause vapor-lock troubles. Information on vapor lock in typical fuel-feed systems will be presented in the near future.

The investigation of the properties of gasolines with reference to vapor lock was subdivided into a number of phases which covered measurements on the vapor pressures of the liquid hydrocarbon constituents including propane (called the gas-free vapor pressure), on the solubility of propane, on the effects of dissolved gases and on the solubility of water. Experimental data are presented on all of these phases of the investigation, including gas-free vapor-pressure values on 43 diverse gasolines and blends.

The general conclusion is reached that the gas-free vapor pressure is essentially the only property of a gasoline which determines the tendency of the fuel to cause trouble from vapor lock. Two practical methods for the determination of the gas-free vapor-pressures are outlined, substantiated by experimental data.

[Major subjects discussed following the paper's presentation include the likelihood of having a fairly large percentage of propane in gasoline, a description of the Reid method, and the temperatures actually existent in the fuel lines. Experiences regarding vapor-lock trouble on motorcoaches and motor-trucks are related, and assertions are made as to what constitutes a good fuel system. The danger of using fuel-feed lines that are too small is mentioned, and the question is raised whether trouble due to supposed vapor-lock may not be caused by some other condition such as the suspension of some derivative of sulphur in the fuel.—Ed.]

THERE is a practical limit to the richness of mixture which it is feasible to supply to the engine in starting. This limit determines the temperature below which starting will not be easy with any given fuel. If starting at lower temperatures is desired, a more volatile fuel is needed. On the other hand, the more volatile a fuel, the greater will be the tendency to boil in the fuel-feed system as the engine warms up. If the fuel boils, then interruptions of flow due to vapor lock may be expected. These two effects—ability to start the engine and ability to keep the engine running when warmed up—impose limits on the practical operating range of fuel temperatures in the fuel-feed system. This practical range is about 140 deg. fahr. for automobiles and similar motor-vehicles.

The property of a gasoline which determines both the starting ability and the tendency to boil is the 10-per cent point; namely, the temperature at which 10 per cent of the gasoline is evaporated in the standard distillation-test. A fuel with a 10-per cent point of 140 deg. fahr. would permit an engine in good mechanical condition to be started easily down to temperatures of 0 deg. fahr. This fuel will boil if heated above its 10-per cent point, which is 140 deg. fahr. in the present instance. Some fuels containing undesirable amounts of propane may cause vapor lock at temperatures 20 deg. fahr. below the 10-per cent point, and some poorly designed fuel systems may also result in interruption of flow at temperatures below the 10-per cent point due to trapping of gases which come out of solution.

In the case of airplanes, the temperature at which boiling may occur becomes lower as the height from the ground increases, due to decrease in the atmospheric pressure. An allowance must be made for a lowering below the 10-per cent point of about 2 deg. fahr. for every 1000-ft. altitude above sea-level. Thus, for an airplane with a ceiling of 20,000 ft., the practical operating range of fuel temperature is reduced to about 100 deg. fahr. A still further lowering is desirable if long suction lifts by a fuel pump are involved.

The practical conclusions which have tentatively been reached can be summarized as follows:

(1) It is undesirable to use a fuel which has a much lower 10-per cent point than that required for easy starting at the lowest temperature likely to be encountered. This may make it desirable to use different grades of gasoline for certain types of operating conditions.

(2) The temperature of the liquid fuel should not exceed the 10-per cent point temperature of the gasoline. Fuel lines should be so designed and installed that they will meet this requirement with a reasonable margin of safety for variations in existing fuels.

(3) The presence of more than small amounts of propane in gasoline is undesirable from the standpoint of vapor lock. If gasolines containing much propane are liable to be used, a liberal margin of safety below the 10-per cent point should be allowed in fixing the maximum operating fuel-temperature which is permissible.

These conclusions are based on the work done up to the present time on the various phases of the investigation of vapor lock. The present paper covers all data obtained on the properties of gasolines which affect

[1] Publication approved by the Director of the Bureau of Standards of the U. S. Department of Commerce.

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their vapor-locking tendency. Data have also been obtained on the temperatures at which vapor lock actually occurs in typical fuel-feed systems, both at sea-level and at altitude, and a report on the results of these experiments will be presented in the very near future. Temperatures in the fuel lines of several representative aircraft during flight have been measured and arrangements have been made for securing additional values. It is planned to extend this investigation to include the measurement of temperatures in automobile fuel-feed systems.

It is hoped that the work outlined will give much information of value on the design and installation of fuel-feed systems in both airplanes and motor-vehicles, and on the types of fuels which are satisfactory for use in existing systems.

Analysis of the Vapor-Lock Problem

Vapor lock is the partial or complete interruption of gasoline flow in the fuel-feed system resulting from the formation of bubbles of vapor or gas. Vapor lock may result when the sum of the pressures exerted by the liquid hydrocarbons, the dissolved gaseous hydrocarbons, dissolved air and water exceeds the external pressure at any point in the fuel system. The higher the temperature of the fuel, the more readily does vapor form under constant external pressure. At a given temperature, lowering of the external pressure favors the formation of vapor. Further, hydrostatic tension, such as occurs in suction lift by a fuel pump, assists vapor formation; whereas hydrostatic pressure, as in gravity feed, retards vapor formation.

Vapor lock cannot possibly occur at any point in the fuel-feed system if the total vapor-pressure of the gasoline flowing through the fuel-feed line, including the pressures of dissolved gases and water, is less than the external pressure at each point in the system. If the total vapor-pressure does exceed the external pressure at any point, there is the possibility that vapor lock will occur. Whether serious interruption of flow occurs will depend upon the decrease in the total vapor-pressure with increase in the size of bubble, upon the characteristics of the gasoline, upon the restrictions offered to the elimination of gas or vapor from the fuel line, and possibly to some extent upon other features of the fuel system.

The investigation of vapor lock can therefore be logically subdivided into three phases:

(1) Study of the vapor pressures of gasolines as a function of temperature, including the effect of dissolved gases and dissolved water.

(2) Determination of the conditions under which vapor lock actually occurs in typical fuel-feed systems.

(3) Measurement of the temperatures existing in representative fuel-feed systems under conditions of operation.

The first phase gives the predicted conditions under which a given fuel theoretically can cause trouble from vapor lock. The second phase gives the actual conditions under which this gasoline does interrupt fuel flow in typical feed systems. Although this second phase of the investigation is still in progress, the results to date show remarkable agreement between the predicted limiting conditions and those actually found in the flow experiments to cause vapor lock. The third phase gives information on the types of fuels necessary to ensure freedom from vapor lock in existing fuel systems.

The present report covers the first phase of the vapor-lock investigation. Data are presented on the gas-free vapor-pressures of 43 fuels over a range of temperatures. These include 2 benzene blends, 5 pentane blends, 4 butane blends and 12 propane blends. Results obtained in the study of the solubility of propane, air, and water in gasolines are given, and their effect on the vapor-locking tendency of a fuel is pointed out. Values for the amounts of ethane and carbon dioxide in a number of gasolines are also included. General conclusions are presented regarding criteria for the evaluation of the tendency of a gasoline to give trouble from vapor lock.

The Vapor-Pressure Problem

From the standpoint of vapor lock, it is desired to know the total vapor-pressures of gasolines, as they are in the fuel-feed system at the instant when bubble formation occurs and with various sizes of bubbles. Three methods are available, namely:

(1) Use of one of the industrial vapor-pressure methods.

(2) Measurement of the vapor pressures of the gasolines, without removal of any constituents, at various temperatures and with various volumes of vapor space.

(3) Measurement of the vapor pressures of the gasolines, after removal of dissolved gases and dissolved water, at various temperatures and with various volumes of vapor space, followed by a study of the effect of dissolved gases and water on the gas-free vapor-pressures thus measured.

The first method was not adopted because there were no criteria regarding the absolute accuracy of the industrial methods; because the effect on the results of the large vapor space employed was not known; and because there were certain limitations to their use for the study of the effects of temperature and volume of vapor space. The second method likewise was not adopted for the reason that all gasolines stored for a sufficient period of time at a given temperature in contact with the atmosphere have a total vapor-pressure, with a small bubble present, equal to that of the atmosphere at this temperature, regardless of their composition or differences in other respects. Hence, although a series of gasolines might show different total vapor-pressures at temperatures other than that of storage and at different volumes of vapor space, the data so obtained would be inherently difficult to interpret. Accordingly, the third method outlined above was adopted.

The vapor-pressure problem therefore resolves itself into a study of the pressures exerted individually by various constituents or various groups of constituents present in the gasolines. For this purpose, a gasoline may be subdivided into (*a*) liquid hydrocarbons, including propane; (*b*) propane; (*c*) ethane; (*d*) methane; (*e*) air; (*f*) carbon dioxide; and (*g*) water. Since propane is on the border line between a liquid and a gas, it is included in both (*a*) and (*b*). Although methane is listed as a possible constituent of gasolines, combustion analyses of the dissolved gases showed that there was no detectable amount present in any of a considerable number of fuels investigated; and hence no further consideration was given to the effect of methane. With this exception, data obtained on all of the constituents enumerated above are considered in the order listed.

Vapor Pressures of Gas-Free Gasolines

The methods used in the preparation of the dry, gas-free gasolines and in the measurement of their vapor pressures over a range of temperatures have been described previously[4], so that a brief outline of them will suffice for the present purpose.

The gasolines were dried by shaking with phosphorus pentoxide, after which they were transferred to the apparatus employed for the removal of dissolved gases. In this procedure, the gasoline was frozen by means of liquid air, the uncondensed residual gases were pumped off, and the gasoline was warmed again to room temperature. This cycle of operations was repeated until the residual pressure, after freezing and before pumping, was reduced to 0.0015 mm. of mercury (0.00003 lb. per sq. in.). When this stage was reached, the gases were considered to have been removed. The U-tube containing the frozen gasoline was then sealed off from the rest of the apparatus and was inverted so that the sample was confined with mercury. It should be noted that the method described does not remove propane, so that any of this constituent present in the original gasoline remained in the gas-free sample.

In making the vapor-pressure measurements, the U-tube containing the gasoline was placed in a thermostated bath at the desired temperature and connection was made to a mercury manometer. The pressure on the gasoline was reduced until vapor formed and pressure readings were made with a very small bubble of vapor present until constancy to 1 mm. was attained. Similar readings were taken at a sufficient number of temperatures to cover the desired pressure-range.

A description of all of the gasolines on which data were obtained is given in Table 1. While these fuels were not purchased in the open market and are not necessarily representative of commercial products, it is believed that the gas-free samples prepared from them are representative. Distillation data on these fuels are given in Table 2. For comparative purposes, the same specification points are used for the aviation fuels as for the motor fuels, and all temperatures correspond to given percentages evaporated. In this table, the fuels are divided into three groups on the basis of vapor-pressure results which will be discussed later in this section. Distillation curves for certain types of these fuels are shown in Figs. 1 to 5, inclusive.

It was found that the vapor-pressure data on each sample could be represented by straight lines if the logarithms of the vapor pressures were plotted against the reciprocals of the corresponding absolute temperatures. The equations of the lines, thus obtained, can be expressed in the form

$$\log (p/760) = A\,[1 - (T_n/T)] \qquad \textbf{(1)}$$

where p is the vapor pressure in millimeters of mer-

[4] See S.A.E. JOURNAL, May, 1929, p. 488.

TABLE 1—DESCRIPTION OF GASOLINE SAMPLES

Fuel	Source	Remarks
S	Bureau of Standards	1928 U. S. Motor gasoline
D2, *E2*	The Texas Co.	Special blends for acceleration work
RH, *RL*	Vacuum Oil Co.	Russian naphthas, Grozny crude
R	Bureau of Standards	Blend of residues
T		Blend 80 per cent *S* and 20 per cent chemically pure benzene
U		Blend 60 per cent *S* and 40 per cent chemically pure benzene
V		Blend 80 per cent *S* and 20 per cent cleaners' naphtha
B2	Army Air Corps	1927 domestic aviation gasoline
10	Naturaline Co. of America	Natural gasoline aviation fuel
11	Phillips Petroleum Co.	Natural gasoline aviation fuel
12	Virginian Gasoline & Oil Co.	Natural gasoline aviation fuel
13	Standard Oil Co. of Cal.	Aviation gasoline
14	Standard Oil Co. of N. J.	Aviation gasoline
15	Standard Oil Co. of Ind.	Aviation gasoline
16	Bureau of Standards	Special blend
17	American Oil Co.	Aviation gasoline
18	The Atlantic Refining Co.	Aviation gasoline
19	Phillips Petroleum Co.	Natural gasoline aviation fuel
21	Bureau of Standards	90 per cent No. 15 and 10 per cent pentane (technical)
22		80 per cent No. 15 and 20 per cent pentane (technical)
23	Bureau of Standards	95 per cent No. 15 and 5 per cent butane (technical)
24		90 per cent No. 15 and 10 per cent butane (technical)
25		85 per cent No. 15 and 15 per cent butane (technical)
26		80 per cent No. 15 and 20 per cent butane (technical)
27	Bureau of Standards	Blend No. 15 with 4.7 per cent propane (app.)
28		Blend 25 per cent No. 15 and 75 per cent No. 27
29		Blend 50 per cent No. 15 and 50 per cent No. 27
30		Blend 75 per cent No. 15 and 25 per cent No. 27
31	Bureau of Standards	Blend No. *S* with 0.7 per cent propane (app.)
32		Blend 50 per cent No. *S* and 50 per cent No. 31
33	Bureau of Standards	Blend No. 12 with 2.8 per cent propane (app.)
34		Blend 50 per cent No. 12 and 50 per cent No. 33
35		Blend 75 per cent No. 12 and 25 per cent No. 33
36	Bureau of Standards	Blend No. 19 with 0.5 per cent propane (app.)
40	Richfield Oil Corp.	Aviation gasoline
41	Phillips Petroleum Co.	Special blend
37	Bureau of Standards	Blend 50 per cent No. 19 and 50 per cent No. 41
60	Phillips Petroleum Co.	Special blend
61, 62, 63	Bureau of Standards	Special pentane blends

TABLE 2—DISTILLATION DATA FOR GASOLINES AND BLENDS

	10 Per Cent		50 Per Cent		90 Per Cent				
Fuel	Deg. Cent.	Deg. Fahr.	Deg. Cent.	Deg. Fahr.	Deg. Cent.	Deg. Fahr.	Per Cent Loss	Per Cent Residue	60 Deg./60 Deg. Specific Gravity
				Group (*a*)					
S	68	154	135	275	195	383	1.7	1.4	0.749
D2	91	196	122	252	203	397	0.8	1.2	0.754
E2	86	187	139	282	200	392	1.9	1.3	0.761
RH	85	185	126	259	168	334	0.5	1.1	0.739
RL	70	158	103	218	147	297	0.3	1.2	0.724
R	98	208	143	289	202	396	1.0	1.0	0.766
T	70	158	111	232	188	370	1.5	1.4	0.772
U	73	163	91	196	181	358	1.4	1.4	0.797
V	78	172	149	300	195	383	1.5	1.2	0.756
B2	67	153	102	216	133	271	1.5	1.3	0.716
10	42	108	63	145	110	230	2.3	0.9	0.677
11	53	127	70	158	113	235	1.7	1.3	0.684
12	68	154	79	174	110	230	0.4	1.8	0.695
13	68	154	93	199	124	255	1.3	1.3	0.733
14	64	147	101	214	136	277	1.9	1.1	0.717
15	68	154	101	214	139	282	1.4	1.3	0.718
16	66	151	72	162	85	185	0.5	0.5	0.695
17	63	145	95	203	135	275	1.0	1.3	0.728
18	61	142	94	201	135	275	1.8	1.2	0.714
19	48	118	65	149	110	230	1.6	1.2	0.682
21	58	136	97	207	139	282	1.9	1.1	0.711
22	50	122	90	194	136	277	2.9	1.1	0.702
23	56	133	100	212	139	282	2.7	1.2	0.714
24	46	115	97	207	137	279	5.0	1.1	0.706
25[a]	38	100	95	203	136	277	2.6	1.0	0.698
26[a]	33	91	91	196	135	275	3.7	1.0	0.696
				Group (*b*)					
27[a]	...	...	99	210	139	282	12.0	1.0	0.706
28[a]	46	115	99	210	138	280	8.0	1.0	0.709
29[a]	54	129	100	212	137	279	5.4	1.0	0.712
30[a]	62	144	100	212	138	280	2.7	1.0	0.715
31[a]	59	138	129	264	192	378	3.2	0.8	0.751
32[a]	62	144	129	264	191	376	2.5	1.0	0.752
33[a]	50	122	75	167	106	223	6.4	1.1	0.683
34[a]	62	144	75	167	107	225	4.1	0.9	0.687
35[a]	66	151	76	169	107	225	1.5	1.0	0.690
36[a]	46	115	64	147	110	230	1.5	1.0	0.680
37[a]	59	138	94	201	131	268	1.6	1.2	0.708
40	63	145	100	212	136	277	1.9	0.6	0.728
41	88	190	120	248	132	270	1.0	1.0	0.736
				Group (*c*)					
60	54	129	154	309	183	361	1.0	0.7	0.740
61	43	109	108	226	134	273	2.0	1.0	0.702
62	43	109	119	246	144	291	1.1	0.9	0.705
63	38	100	158	316	172	342	1.4	0.9	0.722

Note: All temperatures refer to percentages evaporated.

[a] A.S.T.M. Stardard Method D216-27 used. In all other cases, A.S.T.M. Standard Method D86-27 was employed.

TABLE 3—SUMMARY OF VAPOR-PRESSURE DATA ON GAS-FREE SAMPLES

Fuel	Value of *A*	Normal Bubble-Point Deg. Cent.	Normal Bubble-Point Deg. Fahr.	Average △
		Group (*a*)		
S	3.74	68.0	154.4	2.4
D2	3.85	90.0	194.0	1.0
E2	3.91	87.5	189.5	2.4
RH	4.00	86.2	187.2	0.4
RL	3 84	67.7	153.9	1.0
R	3.83	99.1	210.4	1.0
T	4.01	69.7	157.5	1.0
U	3.97	71.0	159.8	2.0
V	3.67	77.2	171.0	2.4
B2	3.97	65.3	149.5	0.8
10	4.23	41.5	106.7	2.2
11	4.31	52.4	126.3	3.3
12	4.21	66.6	151.9	2.5
13	4.14	68.4	155.1	1.7
14	3.84	63.0	145.4	1.1
15	4.04	69.1	156.4	1.3
16	4.47	65.5	149.9	1.0
17	4.03	61.6	142.9	0.6
18	4.09	60.7	141.3	1.3
19	4.26	48.2	118.8	2.0
21	4.01	56.8	134.2	1.6
22	3.97	50.6	123.1	1.0
23	3.92	56.3	133.3	1.2
24	3.88	45.6	114.1	1.3
25	4.04	39.0	102.2	0.5
26	4.04	32.9	91.2	2.0
		Group (*b*)		
27	3.39	24.2	75.6	1.0
28	3.36	30.0	86.0	0.8
29	3.43	38.0	100.4	1.0
30	3.54	48.6	119.5	0.0
31	3.46	56.1	133.0	1.7
32	3.55	60.0	140.0	0.3
33	3.44	37.2	99.0	1.0
34	3.59	53.3	127.9	0.0
35	3.82	59.9	139.8	0.0
36	4.21	45.0	113.0	1.3
37	4.13	59.9	139.8	1.0
40	3.69	56.8	134.2	1.0
41	3.33	76.9	170.4	1.0
		Group (*c*)		
60	4.11	62.5	144.5	1.0
61	4.12	43.0	109.4	0.3
62	3.93	44.1	111.4	0.0
63	4.00	46.9	116.4	0.7

cury, A is a specific constant for each gasoline and T_n and T are temperatures in degrees absolute (degrees centigrade + 273.1 or degrees fahrenheit + 459.6). T_n is the normal bubble-point; namely, the temperature at which the vapor pressure equals one atmosphere. Values of A and T_n were obtained analytically from the data on each fuel.

The vapor-pressure data secured on the 43 gasolines and blends are summarized in Table 3. Figures in the column designated by "Average △" represent in each case the average deviation between the observed pressures and those computed from equation (1), using the appropriate values of A and the normal bubble-point. These deviations are seen to be small, and the grand average deviation over the whole set of data is only 1.2 mm. of mercury or 0.023 lb. per sq. in.

A comparison of the observed normal bubble-points of the group (a) fuels with the 10-per cent points of the same fuels, recorded in Table 2, is made in Fig. 6. This plot indicates that the normal bubble-points of such fuels are numerically equal to the 10-per cent points within experimental error, the average deviation from equality being 0.9 deg. cent. (1.6 deg. fahr.) which is within the accuracy of the A.S.T.M. distillation-method. This agreement makes it possible to substitute $T_{10\text{ per cent}}$ for T_n in equation (1), which then becomes

$$\log (p/760) = A\,[1 - (T_{10\text{ per cent}}/T)] \qquad \text{(1A)}$$

A study of the values of A for the group (a) fuels yields the additional information that they are a function of the normal bubble-points or 10-per cent points, and the slopes of the A.S.T.M. distillation curves at the 10-per cent points. This relation can be expressed in the following form:

$$A = 3.41 + 3.8 \times 10^{-3}\, T_{10\text{ per cent}} - 0.6 \sqrt{S} \qquad (2)$$

where $T_{10\text{ per cent}}$ is in absolute centigrade degrees, and S is the slope at the 10-per cent point expressed in terms of degrees centigrade per unit per cent evaporated. The agreement between the observed values of A and those computed by means of equation (2) is shown in Table 4 for the 26

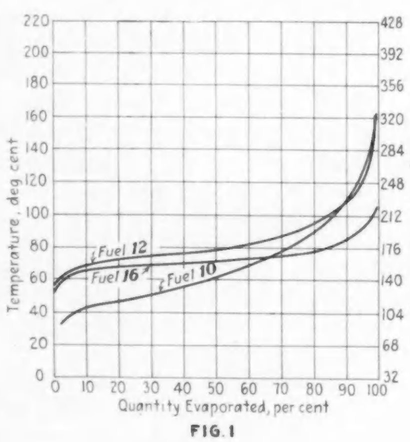

FIG. 1

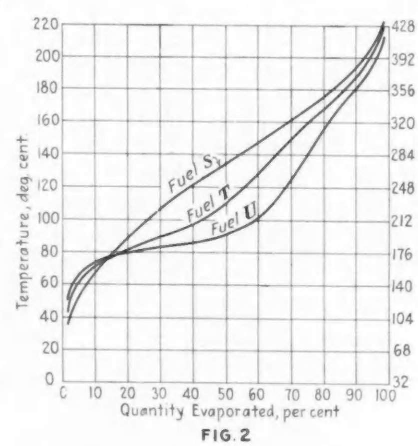

FIG. 2

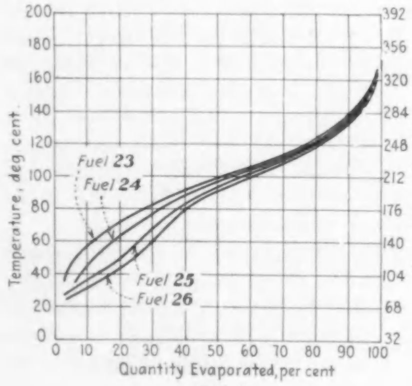

FIG. 3

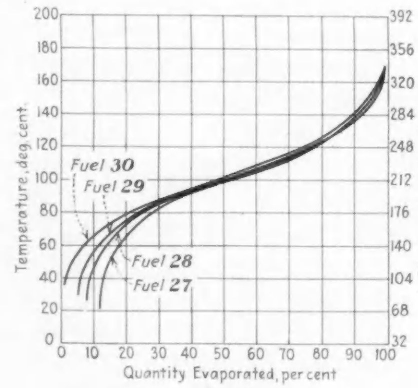

FIG. 4

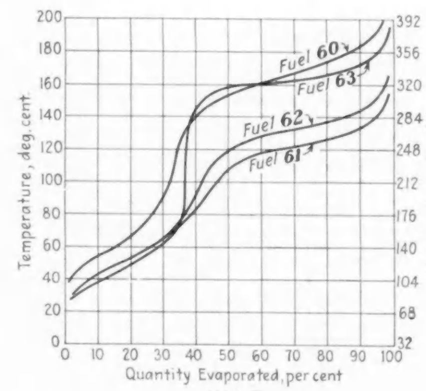

FIG. 5

A.S.T.M. DISTILLATION CURVES

For Natural Gasoline, Fig. 1; Benzene Blends, Fig. 2; Butane Blends, Fig. 3; Propane Blends, Fig. 4; and Special Pentane Blends, Fig. 5

fuels which are enumerated in group (*a*).

For practical purposes, such as the application of vapor-pressure data to the prediction of vapor-locking temperatures, equations (1A) and (2) may be used to compute the vapor pressures of fuels, similar to those studied, from the A.S.T.M. distillation data. A comparison of the observed values in pounds per sq. in. at 32.2 deg. cent (90 deg. fahr.) with those calculated from the 10-per cent point relations is made in Table 5. The agreement is good between the two sets of values for the group (*a*) fuels, the average deviation being 0.18 lb. per sq. in.

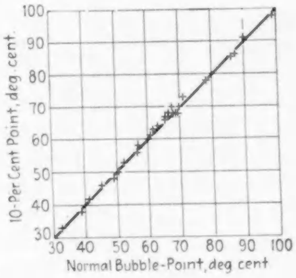

FIG. 6 — COMPARISON OF NORMAL BUBBLE - POINTS WITH 10-PER CENT POINTS FOR GROUP (*a*) FUELS

The evaluation of the vapor pressures of such fuels at either 32.2 deg. cent (90 deg. fahr.) or 37.8 deg. cent (100 deg. fahr.) may conveniently be made by means of the alignment charts shown in Figs. 7 and 8. The first chart is based on equation (1A) and is used to determine the value of *A* from the 10-per cent point and the slope of the distillation curve at this point. The second chart, based on equation (2), is used to evaluate the vapor pressure from the value of *A*, read from the first chart, and from the 10-per cent point. The left-hand side of the temperature scale is for the evaluation of vapor pressures at 100 deg. fahr.; whereas that on the right-hand side is for vapor pressures at 90 deg. fahr. For average gasolines, the second chart can be used directly, assuming $A = 4.0$.

An illustration will make clear the method of using the charts. It is desired to know the vapor pressure at 100 deg. fahr. of a gasoline having a 10-per cent point of 52 deg. cent., and having a slope at the 10-per cent point of 1.2. To find the value of *A* from Fig. 7, connect 52 on the 10-per cent point scale with 1.2 on the *S* scale by means of a straight edge, and the intersection of the line with the *A* scale gives the value of *A*; namely, 4.0. To obtain the vapor pressure at 100 deg. fahr., connect 52 on the left-hand 10-per cent point scale of Fig. 8 with 4.0 on the *A* scale by means of a straight edge, and extrapolate this line to cut the *P* scale. The intersection at 10 lb. per sq. in. is the desired vapor pressure. The corresponding value at 90 deg. fahr. is 8.3 lb. per sq. in.

TABLE 4—OBSERVED AND CALCULATED VALUES OF *A* FOR GROUP (*a*) FUELS

Fuel	10-Per Cent Point Deg. Cent.	10-Per Cent Point Deg. Fahr.	*S*	Value of *A* Calculated	Value of *A* Observed	△
S	68	154	2.6	3.74	3.74	0.00
D2	91	196	2.0	3.95	3.85	— 0.10
E2	86	187	2.3	3.87	3.91	0.04
RH	85	185	1.7	3.99	4.00	0.01
RL	70	158	1.6	3.96	3.84	— 0.12
R	98	208	2.0	3.97	3.83	— 0.14
T	70	158	1.6	3.96	4.01	0.05
U	73	163	1.1	4.10	3.97	— 0.13
V	78	172	3.0	3.71	3.67	— 0.04
B2	67	153	1.8	3.90	3.97	0.07
10	42	108	0.7	4.11	4.23	0.12
11	53	127	0.5	4.22	4.31	0.09
12	68	154	0.7	4.21	4.21	0.00
13	68	154	1.3	4.03	4.14	0.11
14	64	147	1.7	3.92	3.84	— 0.08
15	68	154	1.5	3.98	4.04	0.06
16	66	151	0.4	4.32	4.47	0.15
17	63	145	1.3	4.01	4.03	0.02
18	61	142	1.5	3.95	4.09	0.14
19	48	118	0.7	4.13	4.26	0.13
21	58	136	1.4	3.96	4.01	0.05
22	50	122	1.2	3.98	3.97	— 0.01
23	56	133	2.0	3.81	3.92	0.11
24	46	115	2.4	3.69	3.88	0.19
25	38	100	1.2	3.93	4.04	0.11
26	33	91	1.1	3.94	4.04	0.10
					Grand Average △	0.08

In the vapor-pressure measurements, a very small bubble of vapor was used in each case. In addition to these data, a number of measurements were made with bubbles of various sizes in order to study the change in vapor pressure with volume of vapor space. The procedure used in obtaining these values was the same as that previously described, except that the temperature of each gasoline was adjusted so that the vapor pressure with a small bubble present was in each case a definite value. Then at each constant temperature, pressure readings were made employing various volumes of vapor space. Such sets of experiments were conducted at 600, 400 and 200 mm. initial pressure.

The data obtained in these experiments are shown in Fig. 9. Since the quantities of gasoline in the vapor-pressure tubes varied, the bubble size was expressed for comparability in terms of the variable V/L, where V and L are the volumes of vapor and liquid respectively. Under each set of conditions, a straight line represents the data closely. The equations for these lines are as follows:

$$p = 600 - 15\,(V/L) \qquad \text{(600 mm.)}$$
$$p = 400 - 10\,(V/L) \qquad \text{(400 mm.)}$$
$$p = 200 - 5\,(V/L) \qquad \text{(200 mm.)}$$

These three equations can be combined into the one relation

$$\Delta p = -\,0.025\,(V/L)\,p_o \tag{3}$$

TABLE 5—COMPARISON OF VAPOR-PRESSURE VALUES AT 32.2 DEG. CENT. (90 DEG. FAHR.) BY THREE METHODS

Fuel	Vapor Pressure, Lb. per Sq. In. Bureau of Standards Method	Reid Method[5]	10-Per Cent Point Relations
	Group (*a*)		
S	5.3	...	5.3
D2	2.7	...	2.5
E2	2.9	...	3.1
RH	2.9	...	3.0
RL	5.3	...	4.8
R	2.1	...	2.1
T	4.7	...	4.8
U	4.6	...	4.2
V	4.2	...	4.1
B2	5.5	...	5.3
10	10.9	10.5	10.8
11	7.6	7.9	7.6
12	4.9	6.0	4.7
13	4.7	5.4	5.0
14	6.0	6.5	5.7
15	4.8	5.4	5.0
16	4.8	...	4.9
17	6.0	6.0	5.8
18	6.1	5.6	6.2
19	8.8	8.9	9.0
21	7.0	...	6.8
22	8.5	...	8.6
23	7.2	...	7.4
24	9.9	...	10.0
25	11.9	...	12.4
26	14.4	...	14.4
	Group (*b*)		
28	15.5	...	10.4
29	12.6	...	8.2
30	9.5	...	6.3
31	7.9	7.5	7.2
32	7.0	7.3	6.6
33	12.9	13.2	8.9
34	8.3	8.4	6.2
35	6.6	6.4	5.0
36	9.8	10.2	9.6
37	6.2	6.6	6.8
40	7.4	7.5	6.0
41	4.8	4.2	2.8
	Group (*c*)		
60	5.7	5.5	7.6
61	10.5	11.1	10.7
62	10.3	10.7	10.7
63	9.4	10.0	12.4

[5] Values listed under the Reid method were obtained by multiplication of the Reid vapor-pressures by the factor 1.1.

where p_o is the vapor pressure with an extremely small bubble and Δp is the difference between p_o and the pressure when the ratio of vapor to liquid volume is V/L. Equation (3) appears to be general for all of the group (*a*) fuels over the range investigated, up to $V/L = 1.0$.

The group (*b*) and (*c*) fuels represent samples for which the 10-per cent point relations may not give accurate values for the vapor pressures. The group (*b*) fuels, which contain more than traces of propane, give computed vapor pressures which are lower than the observed values. The group (*c*) fuels, which have A.S.T.M distillation-curves exhibiting an abrupt rise in temperature over a narrow range of percentage evaporated around 30 to 50, give computed vapor pressures which are higher than the observed values.

A comparison of the normal bubble-points and the 10-per cent points of the group (*b*) and (*c*) fuels is given in Fig. 10, where the group (*b*) fuels are designated by solid circles and the group (*c*) fuels by triangles. In the more extreme cases, the normal bubble-points of the group (*b*) fuels are lower than the 10-per cent points; whereas the reverse is true with the group (*c*) fuels. A similar comparison between the observed and calculated values of A is made in Fig. 11, where the deviations are seen to be somewhat erratic. The differences between the measured vapor pressures at 32.2 deg. cent. (90 deg. fahr.) and those computed from the 10-per cent point relations can be observed from Table 5. In some cases, the differences amount to 2 to 5 lb. per sq. in. as compared with an average deviation of 0.2 lb. per sq. in. for the group (*a*) fuels. Thus, although the 10-per cent point relations are satisfactory for a large number of the fuels investigated, there are certain extreme types of fuels for which this practical method of estimating vapor pressures is entirely unsatisfactory.

One of the distinct advantages of the precision method developed at the Bureau of Standards for the determination of vapor pressures lies in its possibilities for use as a standard method for comparing the accuracy of other more practical methods. One such comparison has been discussed above in the case of the 10-per cent point relations. Another practical method which was investigated during the course of this work was the Reid method[6] for the determination of vapor pressures.

It was found that the Reid vapor pressures were generally lower than the values obtained by the more precise

[6] See *National Petroleum News*, Aug. 29, 1928, p. 25.

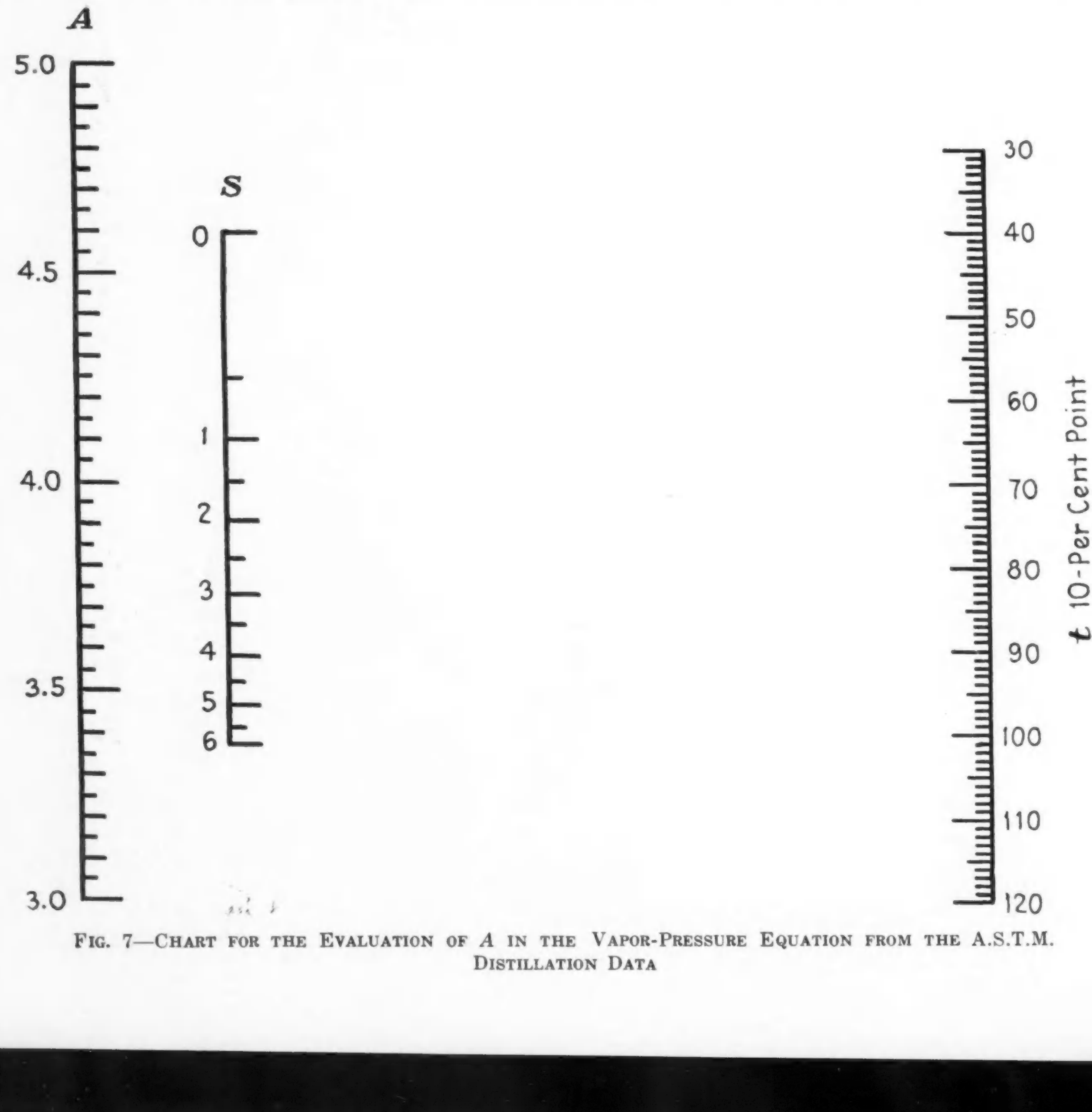

FIG. 7—CHART FOR THE EVALUATION OF A IN THE VAPOR-PRESSURE EQUATION FROM THE A.S.T.M. DISTILLATION DATA

method. This was attributed to the large volume of vapor space in the Reid bomb ($V/L = 4.0$), and hence correction was made for this effect by multiplying all Reid vapor pressures by the factor 1.1, which was obtained from equation (3) by substituting the value of V/L. Corrected Reid values at 90 deg. fahr. on all of the samples studied are shown in Table 5, where a comparison can be made with the gas-free values and those computed from the 10-per cent relations. The agreement between the results obtained by the method developed here and the Reid method is reasonably good, the average deviation being 0.4 lb. per sq. in. This is further illustrated in Fig. 12. It is to be noted that the agreement is equally good for the three groups of fuels. Thus, the Reid vapor-pressure method appears to be more generally applicable than the 10-per cent point method, although it is not so accurate as the latter for those types of fuels for which the 10-per cent point relations hold.

The gas-free vapor pressure of a gasoline indicates the extent to which the liquid hydrocarbons present contribute to the vapor-locking tendency of the gasoline. If no other constituents were present, such as dissolved gases, the temperature at which the gas-free vapor pressure became equal to the pressure on the gasoline in the fuel line would be the temperature at which vapor-lock would occur. In such a case, the vapor-locking temperatures would be given accurately by means of vapor-pressure measurements by the method developed at the Bureau of Standards. With all except extreme types of fuels, these temperatures could be evaluated with considerable accuracy from the 10-per cent point

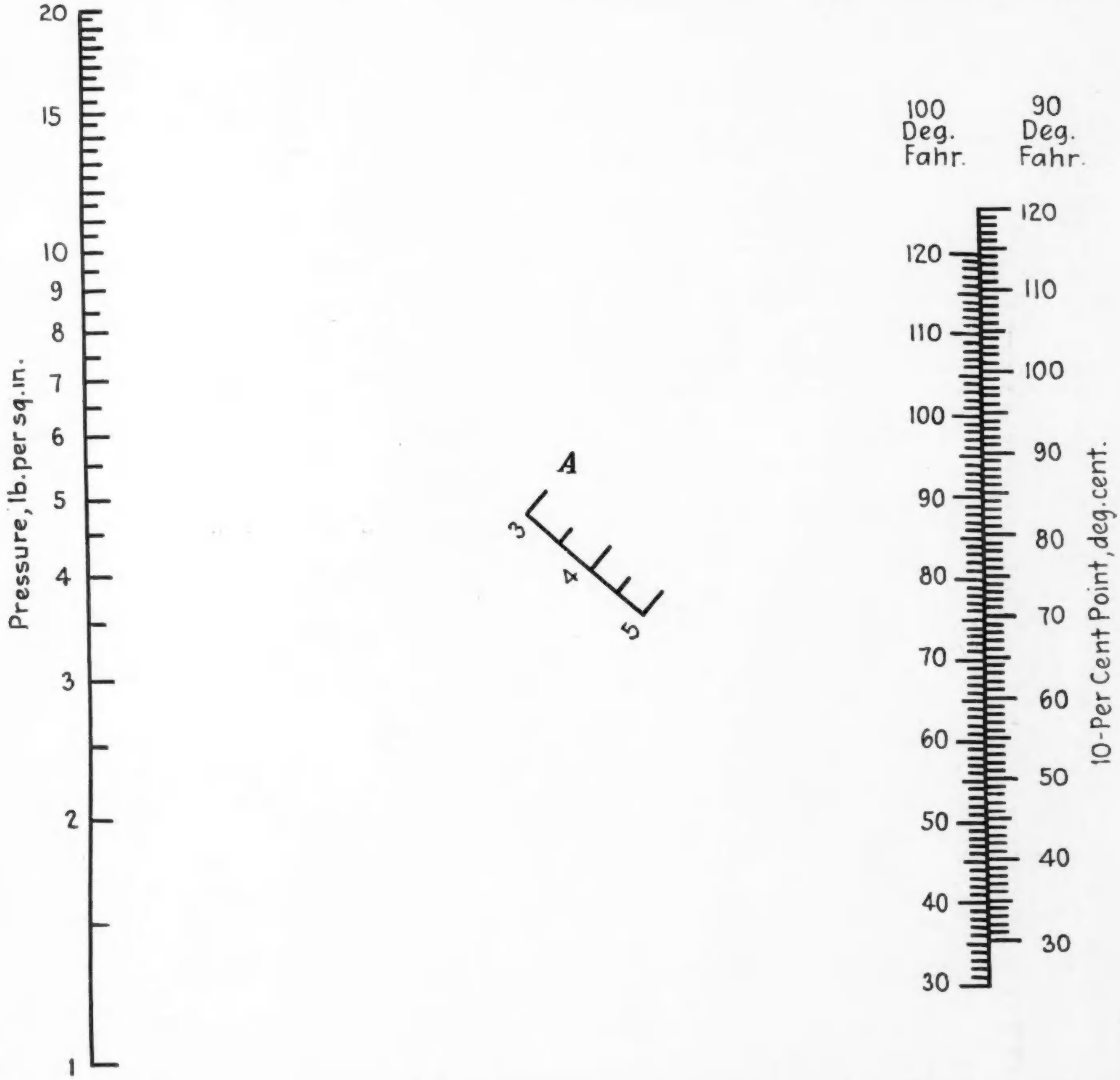

FIG. 8—CHART FOR THE EVALUATION OF THE VAPOR PRESSURES AT 90 DEG. FAHR. AND AT 100 DEG. FAHR. FROM THE 10-PER CENT POINT

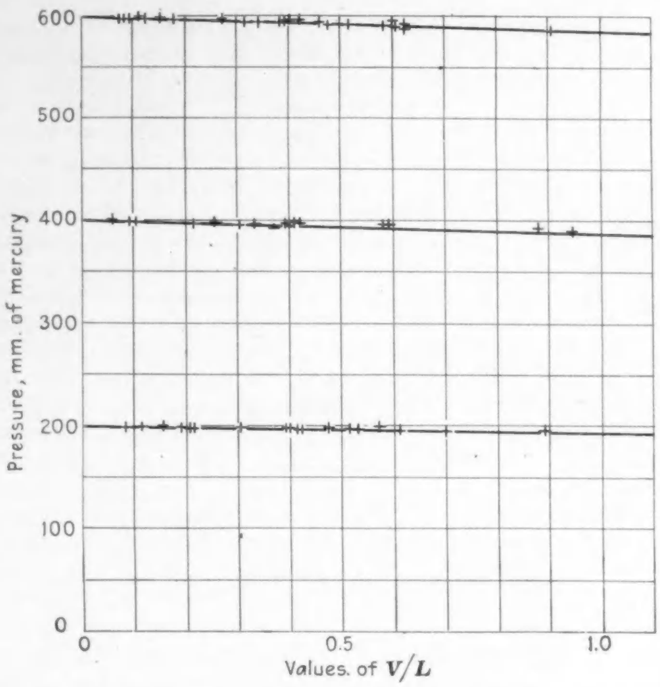

FIG. 9—VARIATION OF VAPOR PRESSURE WITH VOLUME OF VAPOR SPACE

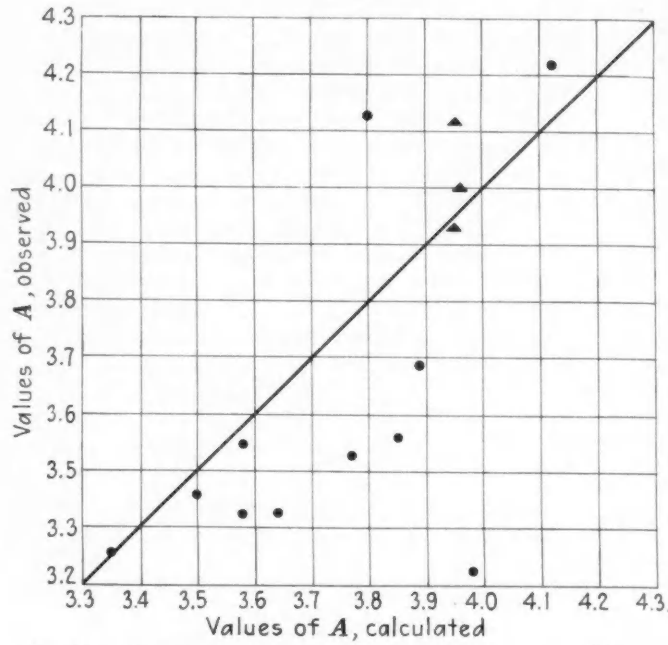

FIG. 11—COMPARISON OF OBSERVED AND CALCULATED VALUES OF A IN THE VAPOR-PRESSURE EQUATION FOR GROUP (b) AND GROUP (c) FUELS

relations. The Reid method, though not very accurate, does appear to provide a practical means for the evaluation of the temperatures under discussion for all of the types of fuels investigated. However, other constituents may have an effect on the vapor-locking tendencies of the gasolines, so that a general discussion of the application of the vapor-pressure data is postponed until the effects of these other constituents are considered.

Solubility of Propane in Gasolines

Since the work on the vapor pressures of propane blends indicated that the addition of small amounts of propane to a gasoline caused a large increase in the vapor pressure, it was considered desirable to investigate this effect further by determining the pressures exerted at various temperatures when known amounts of propane were added to each of several gasolines. Gas-free samples were prepared in special U-tubes provided with a capillary side-arm, the method previously described being used to remove the dissolved gases. The vapor pressures of these samples were then measured at a series of temperatures and with various volumes of vapor space.

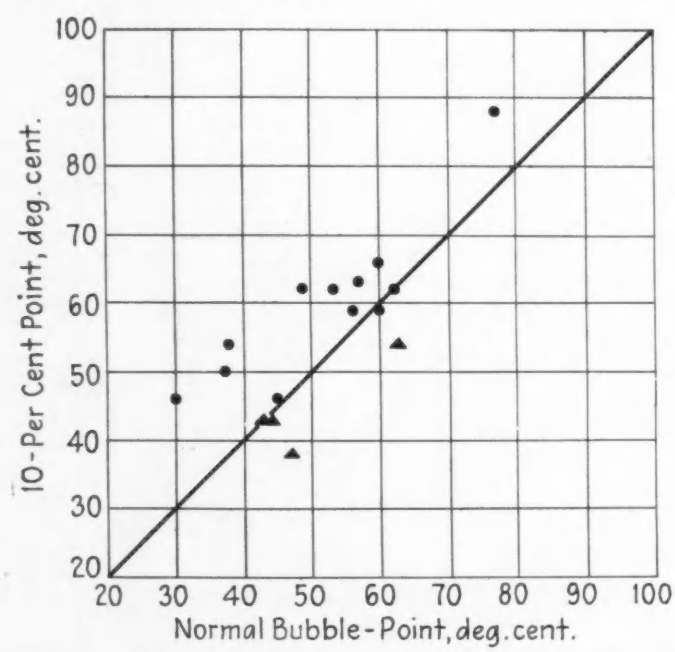

FIG. 10—COMPARISON OF NORMAL BUBBLE-POINTS WITH THE 10-PER CENT POINTS FOR GROUP (b) AND GROUP (c) FUELS

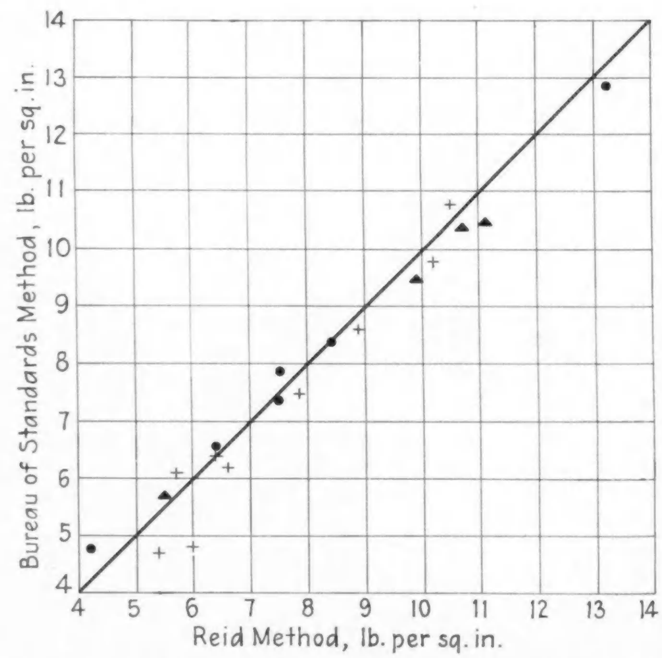

FIG. 12—COMPARISON OF GAS-FREE VAPOR-PRESSURES BY THE BUREAU OF STANDARDS METHOD WITH CORRECTED REID VAPOR-PRESSURES

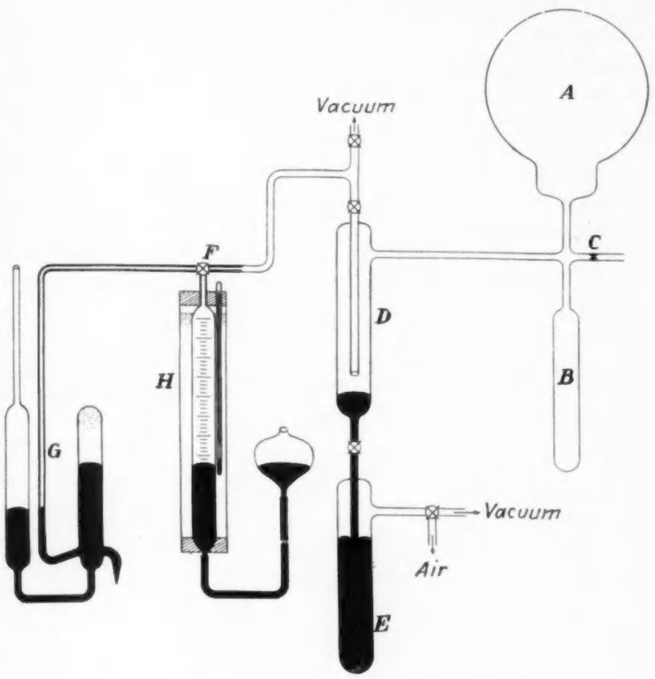

FIG. 13—APPARATUS FOR THE PURIFICATION OF PROPANE AND FOR ITS ADDITION TO THE GAS-FREE GASOLINES

The apparatus used for the purification of the propane and for its addition to the gas-free samples is shown in Fig. 13. An evacuated metal container, fitted with a valve, was filled with commercial propane, which was claimed by the manufacturer to be 98-per cent pure. The container was sealed to the apparatus just beyond the point C and the system of bulbs A and B was thoroughly evacuated. The propane was then liquefied in B by means of liquid air, and the connecting tube to the metal container was sealed off at C. Any gases present were removed by a fractional condensation procedure similar to that employed for removing gases from the gasolines. When the residual pressure above the propane, after cooling to liquid-air temperatures but before pumping, reached a constant value of about 0.002 mm. of mercury, the propane was considered free from gases. It was stored in the gaseous state in the 5-liter bulb A, closed by the mercury valve D shown in the open position. It is recognized that this procedure may not remove all of the ethane present in the original mixture, and will, of course, remove none of the hydrocarbons of boiling-points higher than propane. The presence of the latter group will not materially affect the results of this work.

For the addition of propane to a gasoline sample, the capillary side arm of the U-tube was connected to the 3-way stopcock F, one arm of which led to a measuring burette and the other arm to the bulb containing the propane. These connecting tubes were evacuated and mercury was allowed to rise from both the U-tube and the burette until it was beyond the stopcock in each case. Propane was then admitted to the burette, where its volume was measured at a determined temperature and pressure. By turning the stopcock to the appropriate position, the propane was transferred quantitatively to the gasoline in the U-tube.

The thermostated bath used for keeping the samples at constant temperature during the vapor-pressure measurements is shown in Fig. 14. The temperature was maintained constant by means of the thermo-regulator J which controlled the heat input from the electrical heater K. The expansion of carbon dioxide in the coil L was used to cool the bath when temperatures below that of the room were desired. It was found that agitation of the liquid-vapor interface materially assisted in the attainment of equilibrium, and a motor-driven-cam arrangement was employed for this purpose. The difference in height between the mercury surfaces in the U-tube was read by means of a cathetometer through a glass window in the metal bath, not shown in the diagram.

Measurements were made at 0, 20 and 40 deg. cent. (32, 68 and 104 deg. fahr.) after each addition of propane and with each gasoline. Successive amounts of propane were added in sufficient quantities to cover the desired pressure-range. At each temperature, the vapor pressure of the gas-free gasoline was subtracted from the total pressure to give the partial pressure of the propane. A correction was made in every case for the amount of propane gas present in the vapor space above the liquid.

An example of the type of solubility-pressure plots obtained is shown in Fig. 15, where the pressure of the propane is in millimeters of mercury and the solubility is expressed in grams of propane per 100 grams of gasoline. It is to be noted that the solubility is a linear function of the pressure; or conversely, the pressure exerted at constant temperature by propane in solution in a gasoline is a linear function of the amount present.

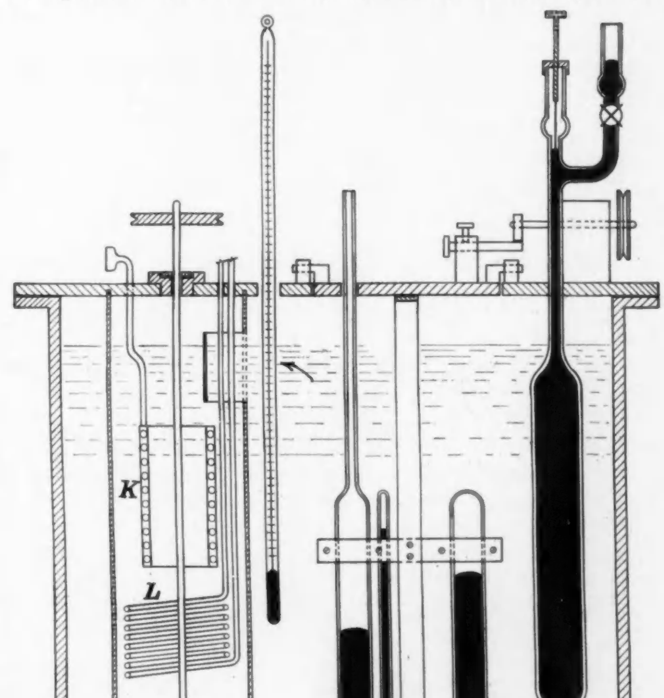

FIG. 14—APPARATUS FOR THE MEASUREMENT OF PROPANE SOLUBILITY

Hence, knowledge of the pressure, p, exerted for any given amount of propane permits evaluation of the pressure for any other amount within the limits investigated. This may be stated analytically in the form

$$\sigma = kp \tag{4}$$

where σ is the solubility expressed as grams propane per 100 grams gasoline, and k is a specific constant dependent upon the temperature and the particular gasoline.

Data were obtained on the solubility of propane in five gasolines over a considerable pressure range, and at the three temperatures previously mentioned. A study of these data indicated that the constant k of equation (4) could be expressed accurately as a function of the temperature by means of the following relation:

$$\log k = a + (830/T) \tag{5}$$

where a is a specific constant for each fuel, and T is the temperature in absolute centigrade degrees. Further, a was found to be related to the 60 deg. / 60 deg. specific gravity ρ of the gasolines according to the equation

$$a = -4.463 - 0.83\,\rho \tag{6}$$

The agreement between the observed values of a and those computed from the equation is illustrated in Fig. 16.

Equations (4), (5) and (6) may be combined to give

$$\log \sigma = \log p - 4.463 - 0.83\,\rho + (830/T) \tag{7}$$

which appears to be a general equation for the solubility of propane in a gasoline. The average deviation between the observed values of σ and those computed from equation (7) amounts to 2 per cent, with a maximum deviation of less than 4 per cent. It is interesting to note that the change in the propane solubility with temperature is very marked, whereas the effect of density is comparatively small.

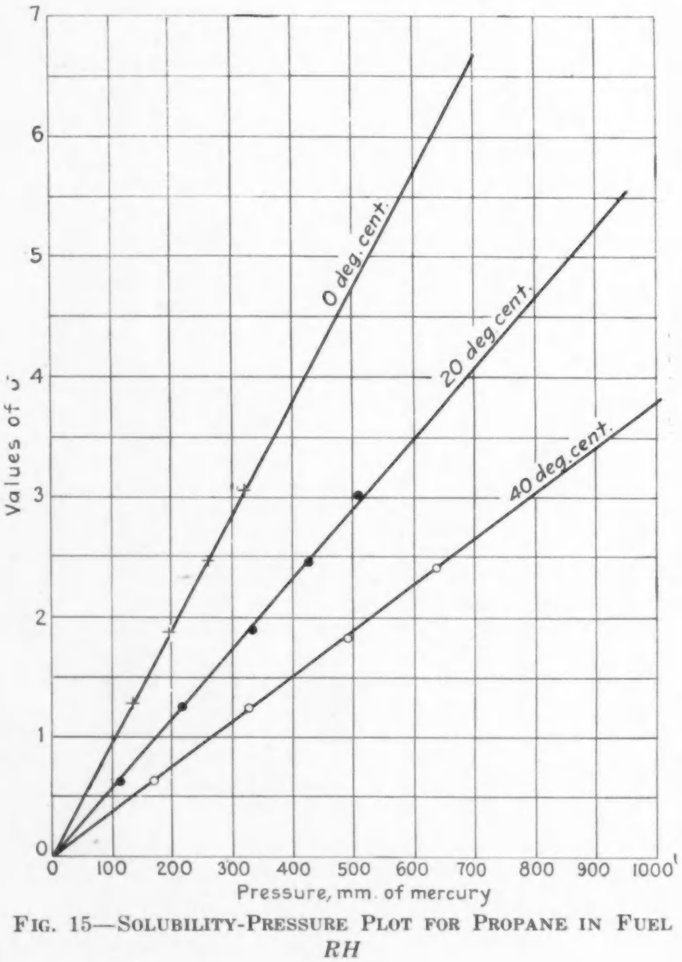

FIG. 15—SOLUBILITY-PRESSURE PLOT FOR PROPANE IN FUEL *RH*

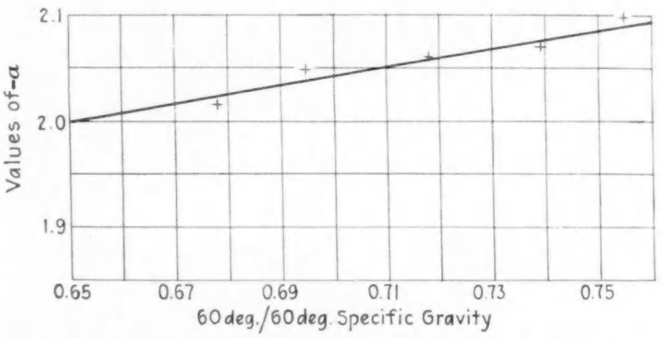

FIG. 16—RELATION BETWEEN a OF PROPANE SOLUBILITY, EQUATION (5) AND THE 60 DEG. / 60 DEG. SPECIFIC GRAVITY OF THE GASOLINE

The solubility may also be expressed in terms of milliliters of propane, measured at 0 deg. cent. (32 deg. fahr.) and 1 atmosphere, per 100 ml. of gasoline, measured at 15.6 deg. cent. (60 deg. fahr.). In this case, equation (7) becomes

$$\log \sigma_v = \log p - 1.757 + (\log \rho - 0.83\,\rho) + (830/T) \tag{8}$$

where σ_v is the solubility on a volume basis.

Equations (7) and (8) give the pressure exerted by propane at any temperature over the range studied, when a known amount of propane is dissolved in a gasoline having a 60 deg. / 60 deg. specific gravity ρ. This pressure is the contribution of the propane to the vapor-locking tendency of the gasoline. In general, however, information is not available regarding the propane content of gasolines.

The desirability of minimizing the amount of propane present in order to avoid vapor lock can be illustrated as follows. A fuel containing 1 gram of propane per 100 grams of gasoline has the equivalent of about 360 ml. of propane gas dissolved in 100 ml. of the gasoline. If the temperature of such a fuel flowing through the feed lines is increased, all of this gas may be liberated and vapor lock would almost certainly result at temperatures considerably below those at which the same gasoline, without propane, would give trouble. If the pressure on the fuel lines is decreased, as in the case of an airplane gaining altitude, similar liberation of gas may occur; only, in this latter case, the volume of gas liberated increases rapidly with lowering of the atmospheric pressure. At the same temperature and with the same fuel, at least twice the volume of gas would probably be liberated in the fuel-feed lines at 18,000 ft. as at sea-level. Although there may be some compensating factors, such as loss of the propane in the fuel tanks, in general the problem of vapor lock with gasolines containing propane is much more serious with airplanes than with automobiles or similar vehicles.

Incidental to the study of propane solubility, a number of values were obtained for the increase in volume of the gasolines on addition of known amounts of propane. These data can be used to evaluate the apparent volume occupied by the propane when dissolved in a

gasoline. The apparent volume occupied at 60 deg. fahr. by 1 gram of propane, called the apparent specific volume, was thereby found to be 2.2. Hence, addition of 1 gram of propane to 100 ml. of a gasoline at 60 deg. fahr. will result in a blend having a volume of 102.2 ml.

Ethane Content of Gasolines

In order to determine whether it was necessary to investigate the pressures exerted by known amounts of ethane dissolved in gasolines, a preliminary survey was made of the ethane contents of a number of gasolines.

The procedure adopted for this investigation consisted in successively freezing 50 ml. of gasoline in a glass container by means of liquid air and allowing it to melt; and, in between each such operation, pumping off the gases by means of a mercury displacement pump until no more gas was evolved. This process permits a separation of ethane, and any methane present, from the propane and heavier hydrocarbons. The volume of gas collected from each gasoline was measured at a known temperature and pressure. The ethane was burned to CO_2 and H_2O in a combustion pipette and measurements were made of the contraction in volume on combustion and the CO_2 formed. There was no evidence of the presence of methane in any of the gas samples collected.

Data on the ethane content of nine gasolines are given in Table 6, expressed both in grams of ethane per 100 grams of gasoline and in milliliters of ethane at 0 deg. cent. (32 deg. fahr.) and 1 atmosphere per 100 ml. of gasoline at 15.6 deg. cent. (60 deg. fahr.). The amounts of ethane found were very small and hence an extension of the work to a study of ethane solubility was not undertaken. It is planned, however, to investigate this latter point in the near future in order to determine the amount of ethane which can be dissolved in gasolines and the pressures which will be exerted by the dissolved ethane at various temperatures.

TABLE 6—ETHANE CONTENT OF GASOLINES

Fuel	Volume, Ml., at Normal Temperature and Pressure, per 100 Ml. of Gasoline	Weight, Grams, per 100 Grams of Gasoline	60 Deg./60 Deg. Specific Gravity
10	2.0	0.0040	0.677
13	2.7	0.0049	0.733
14	1.1	0.0021	0.717
15	1.2	0.0022	0.718
18	2.7	0.0051	0.714
19	1.8	0.0035	0.682
S	0.9	0.0016	0.749
D2	0.6	0.0011	0.754
RH	0.9	0.0016	0.739

Solubility of Air in Gasolines

All gasolines at some time or other normally come in contact with air and hence can dissolve an amount of air sufficient to bring the total vapor-pressure of the air-saturated gasoline, with a small bubble present, up to atmospheric pressure at the temperature of storage. It is for this reason that a series of gasolines stored in contact with the atmosphere will all have the same total vapor-pressure at this temperature regardless of their composition or volatility. The amounts of air required to bring the total vapor-pressure up to that of the atmosphere will be different for different gasolines so that an investigation of the solubility of air in gasolines was undertaken.

The procedure used in adding the known amounts of air to the gas-free samples and in making the vapor-pressure measurements was similar to that described in the work on propane solubility. The solubility of air in six gasolines was obtained over a range of pressures and at the four temperatures, −20, 0, 20 and 40 deg. cent. (−4, 32, 68 and 104 deg. fahr.) with each fuel. At every point, the vapor pressure of the gas-free gasoline was subtracted from the total pressure, giving the partial pressure exerted by the air in solution. The weight of air dissolved in the gasoline under each set of conditions was obtained by subtracting the amount of air in the vapor space above the liquid from the total amount added to the gasoline. Since the weight of each gasoline sample was known, the solubility could be computed in units of weight of air per 100 grams of gasoline.

The change in air solubility with change in air pressure is illustrated in Fig. 17. It is seen that the solubility increases in a linear manner with the pressure of the air similarly to that found for propane. However, in contrast with the propane solubility, which had a marked temperature coefficient, the change in air solubility with temperature is negligible over the range covered from −20 to +40 deg. cent. (−4 to + 104 deg. fahr.). Therefore, for each gasoline, the solubility σ can be expressed by the relation

$$\sigma = kp \qquad (9)$$

where k is dependent only upon the characteristics of the gasoline. A plot of k against the 60 deg. / 60 deg. specific gravity of the fuels, shown in Fig. 18, indicates that for practical purposes k can be related to the gravity ρ by means of the equation

$$k = 2.734 \times 10^{-4} (1 - 1.125 \rho) \qquad (10)$$

Combining equations (9) and (10), the general formula for the solubility of air in gasolines becomes

$$\sigma = 2.734 \times 10^{-4} (1 - 1.125 \rho)\, p \qquad (11)$$

The solubility may also be expressed in terms of milliliters of air, measured at 0 deg. cent. (32 deg. fahr.) and 1 atmosphere, per 100 ml. of gasoline, measured at 15.6 deg. cent. (60 deg. fahr.). In this case, equation (11) can be written

$$\sigma_v = 0.2116\, \rho\, (1 - 1.125 \rho)\, p \qquad (12)$$

where σ_v is the solubility on a volume basis.

Under most conditions, when air is in contact with a gasoline, the total pressure is constant rather than the partial pressure of the air. This is true where gasoline is stored in a tank with a small opening to the atmosphere and is closely true in an airplane fuel-system during steady flight at constant altitude.

With the total pressure constant, the partial pressure of the air is the difference between the total pressure and the vapor pressure of the gas-free gasoline at each temperature; and, since the amount of air in solution depends upon the partial pressure of the air, it is seen that the solubility of air has an apparent temperature coefficient.

Under conditions of constant total-pressure, the amount of air which comes out of solution for a given increase in temperature will be greater with more volatile gasolines. The following table illustrates this point, where the total pressure is 760 mm.

Fuel	Temperature, Deg. Cent.	Pressure, Mm. Gasoline	Air	σ_v	$\Delta\, \sigma_v$
10	20	370	390	13.3	
	40	740	20	0.7	12.6
13	20	168	592	16.1	
	40	360	400	10.9	5.2

TABLE 7—AMOUNT OF CARBON DIOXIDE IN GASOLINES

Fuel	Volume, Ml., at Normal Temperature and Pressure, per 100 Ml. of Gasoline	Weight, Grams, per 100 Grams of Gasoline	60 Deg./60 Deg. Specific Gravity
10	0.045	0.00013	0.677
11	0.090	0.00026	0.684
13	0.050	0.00014	0.733
14	0.073	0.00020	0.717
15	0.084	0.00023	0.718
18	0.073	0.00020	0.714
19	0.050	0.00015	0.682
B2	0.034	0.00009	0.716
C	0.039	0.00010	0.745
D2	0.078	0.00021	0.754

About 2.5 times the volume of air will come out of fuel 10 as out of the same amount of the less volatile fuel 13.

On the other hand, if the temperature of both fuels remained constant at 20 deg. cent. (68 deg. fahr.) while the total pressure was reduced from 760 to 380 mm., the values of σ_v would be as follows:

Fuel	Pressure, Mm. Atmosphere	Gasoline	Air	σ_v	$\Delta\,\sigma_v$
10	760	370	390	13.3	
	380	370	10	0.3	13.0
13	760	168	592	16.1	
	380	168	212	5.8	10.3

About 1.3 times the amount of air would come out of fuel 10 as out of fuel 13 under these conditions. The actual volumes of air liberated will be about twice those given in the table due to the reduction in pressure and the increase in temperature from those used as standard for σ_v.

The work on air solubility indicates that the amount of air liberated in any fuel line under a given set of conditions will be greater with fuels of higher vapor-pressure. However, the volume of air which will come out of solution in any case is considerably less than the volume of the gasoline, so that air should not cause vapor lock in a well-designed fuel system.

Amount of Carbon Dioxide in Gasolines

Although the amount of carbon dioxide present in the atmosphere is very small, some crude oils contain considerable quantities of this gas. Accordingly experiments were made to determine whether the CO_2 content of gasolines was large enough to contribute materially to the vapor pressure. The procedure adopted consisted in shaking 100 ml. of the gasoline in a glass-stoppered flask with a solution of barium hydroxide and titrating with hydrochloric acid the excess alkali left after the reaction with the CO_2 was complete. Bromthymol blue was used as an indicator. Blank runs were made to determine the amount of CO_2 in the air in the flask.

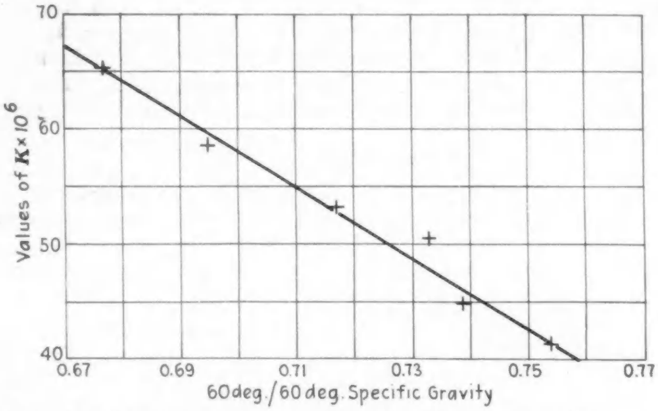

FIG. 18—RELATION BETWEEN k OF AIR SOLUBILITY EQUATION (9) AND THE 60 DEG. / 60 DEG. SPECIFIC GRAVITY OF THE GASOLINE

Data on 10 gasolines are shown in Table 7, expressed both in grams CO_2 per 100 grams of gasoline and in milliliters of CO_2 at 0 deg. cent. (32 deg. fahr.) and 1 atmosphere per 100 ml. of gasoline at 15.6 deg. cent. (60 deg. fahr.). The amounts of CO_2 found are so small as to be negligible from the standpoint of vapor lock.

Solubility of Water in Gasolines

When any gasoline is saturated with water at any given temperature, the pressure exerted by the water in solution is the vapor pressure of pure water at the same temperature, and this is true regardless of the amount of water required for saturation. Water-pressure values above saturated gasolines at a number of temperatures are given below.

Temperature Deg. Cent.	Deg. Fahr.	Pressure Mm. of Mercury	Lb. Per Sq. In.
0	32	4.6	0.09
20	68	17.5	0.34
40	104	55.3	1.07

It is evident from these figures that water dissolved in a gasoline has considerable effect on the vapor pressure. Accordingly, a study was undertaken of the amount of water required to saturate gasolines at several temperatures. The details of the methods used in making these extremely difficult measurements are reserved for future publication so that only a brief outline will be given at this time.

The method used involves (a) saturating the gasoline by shaking with water at a series of constant temperatures; (b) transferring a weighed amount of the water-saturated gaso-

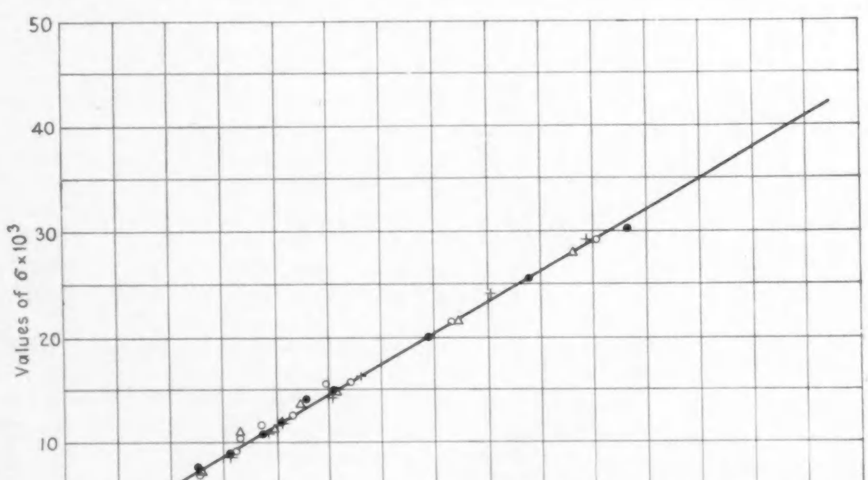

FIG. 17—SOLUBILITY-PRESSURE PLOT FOR AIR IN FUEL NO. 12

line to a suitable container without having gasoline come in contact with the air; (*c*) removing dissolved gases from the gasoline by fractional condensation at liquid-air temperatures; (*d*) adding a liquid sodium-potassium alloy, free from oxide; (*e*) shaking to decompose all of the water with liberation of hydrogen; and (*f*) pumping off the hydrogen gas and measuring it at a known temperature and pressure.

The time required for saturating the gasolines with water was investigated and blank runs were made in which known amounts of water were added to previously dried gasoline samples. The amounts of hydrogen gas obtained were in accord with the quantities of water added.

Data on the solubility of water in five gasolines and at three temperatures are given in Table 8, the values being expressed in grams of water per 100 grams of gasoline. It is to be noted that the solubility is very small and that it decreases as the temperature is lowered. The magnitude of the solubility appears to be specific for each gasoline, probably being dependent upon chemical composition, and no relation between solubility and either gravity or 10-per cent point was apparent. The fact that the solubility is so small warrants the conclusion that gasolines are almost invariably saturated with water at the temperature of storage in contact with the atmosphere. Hence it seems safe to assume that dissolved water contributes almost equally to the pressure required for initial bubble-formation in any gasoline. The contribution to the rate of bubble growth after initial formation has not been ascertained, but it should be very much the same with all gasolines. In any case, the total volume of water vapor formed, even if all of the water present vaporized, would practically never be sufficient to cause vapor lock.

Summary and Conclusions

The investigation of the properties of gasolines with reference to vapor lock was subdivided into a number of phases which covered measurements on the vapor pressures of the liquid-hydrocarbon constituents including propane, on the solubility of propane, on the effects of dissolved gases and on the solubility of water. A summary of the results obtained in this investigation is enumerated below:

(1) A method has been developed for the determination of the gas-free vapor-pressures of gasolines which is accurate and reproducible. While it is too involved for routine tests, it serves as a standard method for evaluating the accuracy of more practical methods. Data are presented on 43 diverse gasolines and blends, obtained by this method.

(2) The results indicated that, in all except extreme cases, vapor-pressure data can be obtained from the A.S.T. M. distillation data. Equations and alignment charts are given for computing gas-free vapor-pressures from the A.S.T.M. 10-per cent points of the fuels. These computed values are accurate to about 0.2 lb. per sq. in. for most gasolines, although deviations of 2 to 5 lb. per sq. in. were obtained with exceptional fuels. Notwithstanding the exceptions, the equations and charts serve a very useful purpose for most types of gasolines.

(3) Reid vapor-pressure values at 90 deg. fahr. on about half of the fuels investigated, including most of the exceptional cases, showed satisfactory agreement with the gas-free values when the former were multiplied by the factor 1.1 to correct for the large volume of vapor space employed in the Reid method. Insofar as the present investigation went, the Reid method appeared to be accurate to better than 0.5 lb. per sq. in., on the average, for all types of fuels.

(4) General equations are given for the solubility of propane in gasolines at three temperatures. At the same pressure, the solubility increases slightly with decrease in the 60 deg. / 60 deg. specific gravity, and increases very rapidly as the temperature is lowered. The apparent specific volume of propane at 60 deg. fahr., found incidentally in the work, is 2.2.

(5) Analysis of nine gasolines indicated that the ethane content varied from 1 to 3 ml. of ethane gas, at 0 deg. cent. (32 deg. fahr.) and 1 atmosphere, in 100 ml. of gasoline. This amount is too small to cause any trouble from vapor lock.

(6) Air dissolves in gasolines in amounts sufficient to bring the total vapor-pressure of the air-saturated sample, with a small bubble present, up to 1 atmosphere. At the same air pressure, more dissolves in gasolines with a lower 60 deg. / 60 deg. specific gravity, but the solubility does not appear to change with temperature over the range studied, from −20 to +40 deg. cent. (−4 to +104 deg. fahr.). The amount of air liberated in a well-designed fuel-feed system is probably not enough to cause vapor lock. In a poorly-designed system, trouble might be encountered.

(7) The amounts of carbon dioxide present in 10 gasolines were found to range from 0.03 to 0.09 ml. of gas, at 0 deg. cent. (32 deg. fahr.) and 1 atmosphere, in 100 ml. of gasoline. This amount is negligible from the standpoint of vapor lock.

(8) The solubility of water in gasolines varies from about 0.005 to 0.02 per cent by weight, and it decreases as the temperature is lowered. The pressure exerted by water is the same in all water-saturated gasolines, and the volume of water vapor liberated in any fuel line would probably never cause vapor lock. However, separation and accumulation of liquid water, if the temperature of the gasoline were lowered, might seriously interrupt the fuel flow.

The experimental work, just summarized, shows that the gas-free vapor-pressure is essentially the only property of a gasoline which is of interest as regards vapor lock in a well-designed fuel-feed system. Such a system is one in which syphons and large air-traps are avoided, in which very long suction-lifts by a fuel pump are avoided, and in which the fuel pump, if employed, is reasonably efficient.

Hence, if the temperature is known at which the gas-free vapor-pressure of any gasoline equals the external pressure on that gasoline in the fuel-feed line, this temperature is the one at which vapor lock with the gasoline may be expected. For most gasolines, the

TABLE 8—SOLUBILITY OF WATER IN GASOLINES

	Grams per 100 Grams of Gasoline, at Temperatures of			10-Per Cent Point		
Fuel	10 Deg. Cent. (50 Deg Fahr.)	30 Deg. Cent. (86 Deg. Fahr.)	50 Deg. Cent. (122 Deg. Fahr.)	Deg. Cent.	Deg. Fahr.	60 Deg./ 60 Deg. Specific Gravity
10	0.013	0.016	0.019	42	108	0.677
12	0.005	0.007	0.007	68	154	0.684
13	0.007	0.007	0.011	68	154	0.733
15	0.006	0.017	0.021	68	154	0.718
19	0.004	0.005	0.006	48	118	0.682

vapor-locking temperature in the fuel line of an automobile will be the 10-per cent point of the gasoline. In airplane fuel-systems, the vapor-locking temperatures will become increasingly lower as the airplane gains in altitude. These temperatures may be computed at any altitude from the atmospheric pressure at this altitude by means of equation (1A). For practical purposes, A may be assumed as 4.0, in which case equation (1A) at 18,000 ft. or 0.5 atmosphere pressure becomes

$$t_{10\text{ PER CENT}} - t = 0.07\, t_{10\text{ PER CENT}} + 33$$

where the temperatures are in degrees fahrenheit, and t is the vapor-locking temperature. For an average gasoline, the temperature at which vapor lock will occur at 18,000 ft. is 44 deg. fahr. lower than at the ground. Very roughly, the vapor-locking temperature is lowered 2 deg. fahr. for every 1000-ft. increase in altitude.

If the Reid method at 100 deg. fahr. is employed for measuring the vapor pressures, then the vapor-locking temperature t in degrees fahrenheit is given by the relation

$$t = 560\left[\frac{5.167 - \log_{10}p_r}{5.167 - \log_{10}p}\right] - 460$$

where p_r is the measured vapor-pressure at 100 deg. fahr. and p is the atmospheric pressure at the given altitude, both in pounds per square inch. Greater accuracy in this application would be obtained by measuring Reid vapor-pressures both at 32 and 100 deg. fahr.

Since the 10-per cent point relations are not accurate for fuels containing more than small amounts of propane, use of the Reid method, or some equally satisfactory method, is preferable for the determination of the vapor pressures of fuels suspected of containing propane. A better solution is to have the gasoline entirely free of propane, especially for aviation use, since small amounts of propane have a marked effect on the vapor pressure and hence on the vapor-locking tendency.

Acknowledgment

This investigation was undertaken as part of a fundamental study of vapor lock in airplane fuel-systems under the direction of the Research Committee of the Society, and was made possible by a contribution from the Naturaline Co. of America. The supervision of this investigation was accepted by the Cooperative Fuel Research Steering Committee in September, 1929, due to the vital importance of the vapor-lock problem to both the petroleum and automotive industries.

THE DISCUSSION

CHAIRMAN W. S. JAMES[7]:—One tangible benefit from the cooperative fuel-research work that was started some time ago at the Bureau of Standards is very often overlooked; it is that it brings into contact the representatives of the automotive and the petroleum industries. Another very definite result has been a unification of the character of gasoline as sold in this Country today, particularly with reference to its volatility.

ROBERT E. WILSON[8]:—The paper refers to the A.S.T.M. 10-per cent point; however, as I recall the actual work, that is not the strict A.S.T.M. 10-per cent point, but is the A.S.T.M. 10-per cent point corrected for loss.

DR. O. C. BRIDGEMAN:—The 10-per cent point referred to is the 10-per cent point on the curve of distillation temperature, plotted against percentage evaporated. It is the temperature of 10 per cent evaporated and not the temperature at 10 per cent distilled as in the ordinary method of plotting the A.S.T.M. curve.

MR. WILSON:—That wording might mislead those who are not familiar with the work and possibly lead them to draw an erroneous conclusion. What is ordinarily called the A.S.T.M. 10-per cent point does not include the loss and it is necessary to make corrections for loss when calculating the vapor-pressure data referred to by Dr. Bridgeman.

WILLIAM G. CLARK[9]:—How much difference exists between the normal 10-per cent point and the corrected 10-per cent point?

DR. BRIDGEMAN:—In average gasolines, 9 deg. fahr.

CHAIRMAN JAMES:—What is the likelihood of having a fairly large percentage of propane in the gasoline under normal manufacturing conditions?

MR. WILSON:—Normal manufacture covers a multitude of sins. Unless the refineries have a compression plant for the recovery of the very light ends from the gases, the ordinary refinery gasolines are not likely to contain more than traces of propane. Gasolines that are made with any considerable proportion of natural gasoline as a blend may, or may not, contain it, depending on the quality of the natural gas which is used. Natural gasolines are made which contain a large percentage of propane; others, of a better quality for blending, contain practically no propane. It is almost impossible to give a definite answer to the question because practice differs so greatly in this respect.

CHAIRMAN JAMES:—Would there be much propane in the cracked gasolines?

MR. WILSON:—Not in the usual cracked distillate. I believe there is no appreciable amount in the distillate that is obtained directly from the cracking operation; but the more efficient refineries take the gases that are produced by cracking and scrub them, or compress them, or by one means or another recover the light ends carried away thereby. Much depends on the type of system and the way in which it is operated for recovering the light ends, regarding whether or not propane will be found in the finished gasoline. One can get propane from the gases end, but not in the ordinary liquid product of cracking.

Reid Method Described

CHAIRMAN JAMES:—What is the Reid method?

DR. BRIDGEMAN:—The Reid apparatus consists of a bomb containing about 100 ml. of gasoline and this is attached to a larger container, at the top of which is a gage, the larger container being filled with air The entire bomb is immersed in a bath at 100 deg. fahr., or 90 deg. fahr., and is allowed to stand with a certain

[7] M.S.A.E.—Research engineer, Studebaker Corp., South Bend, Ind.

[8] M.S.A.E.—Assistant to vice-president in charge of manufacturing; head of development and patent department, Standard Oil Co. of Indiana, Chicago.

[9] M.S.A.E.—Chief automotive and lubricating engineer, Pure Oil Co., Chicago.

amount of shaking for certain periods of time; after this, the vapor pressure is read on the gage. It is just a case of enclosing a certain amount of gasoline within a certain volume and reading the pressures exerted after a certain time. It is a static-pressure method.

Variable 10-Per Cent Points

W. C. BAUER[10]:—In the investigation of vapor lock, the car manufacturer apparently has not considered that the gasoline he actually gets into the carbureter or into the fuel system is not, by a wide margin, the gasoline that is in his storage tank. There have been cases in the laboratory of gasolines taken out of carbureters having the 10-per cent point at least 20 deg. fahr. higher than that of the original fuel. The vacuum tank has a considerable effect; it seems to act as a stripping still, removing the lighter ends of gasoline before they reach the carbureter, and can occasion vapor lock; so, in investigating vapor lock in any particular carbureter, it is necessary to ascertain where the gasoline sample is being taken. Otherwise, very divergent results are likely.

PROF. LEONARD C. PRICE[11]:—The preceding remarks may offer an explanation of an experience of mine with a downdraft carbureter on a Buick car, the car being used first with the stock equipment and a vacuum tank supplied with Texaco gasoline. The engine knocked severely on steep hills; but, after turning the manifold over and using the downdraft carbureter and a fuel pump, the knocking disappeared.

CHAIRMAN JAMES:—Ought that to be blamed upon vapor lock?

PROFESSOR PRICE:—I was alluding to the fact that the vacuum tank stripped off the lighter ends of the gasoline. The absence of the lighter ends probably caused the knock.

Temperatures Existent in Fuel Lines

CHAIRMAN JAMES:—What temperatures actually exist in some fuel lines?

A. M. BABITCH[12]:—Dr. Bridgeman remarked about properly designed and improperly designed systems. What is his definition of such systems? My trouble with carburetion was experienced in some of the hot sections of the Country where the temperature was close to 115 deg. fahr. When idling the engine the temperature of the whole system would immediately become higher and cause trouble, to a point where it would actually stop. Then it is difficult to start the engine again. Cold water must be used to cool the manifold and the carbureter; then, after waiting for some time, the engine probably will start, but that is not always certain.

Tracing the temperatures of the gasoline from the tank to the carbureter reveals a very interesting situation. In California, in addition to the temperature of the air, which in many places is at 115 deg. fahr., one also encounters a reflected air-temperature from the heated sand or concrete, or "road flare" as it is called. This temperature is sometimes as high as 150 to 160 deg. fahr. With this reflected heat during the time between say 11:00 a.m. and 3:00 p.m., the rear tank frequently will heat up to about 140 or 150 deg. fahr. In one instance, with an air temperature of 105 deg. fahr., we had a rear-tank temperature of 145 deg. fahr.

In addition to the road temperature, the heat from the exhaust shoots at the rear tank and causes temperature increase. The gasoline line itself is the most offensive factor in this respect, as most of the fuel lines are carried on the side where the muffler is located. In one instance, where the air temperature did not exceed 94 deg. fahr., the temperature of the air surrounding the fuel line where it crossed a hot pocket actually was 270 deg. fahr. and the gasoline entering the carbureter was at a temperature of 160 deg. fahr.

In many instances, the carbureter itself is a great offender. Before the gas passes the jets it sometimes has to travel through enlargements and, when the gas starts to boil, the vapor formed in the enlargements will totally block the flow of gasoline through the jet.

My experience was in connection with the A. C. Spark Plug Co. gasoline pump. Naturally, for a long time the pump was blamed for all troubles; but after analyzing conditions in detail and calling them to the attention of the engineers, they began to realize that something besides the gasoline pump caused trouble. Therefore, research work has been done on vapor lock and still more is to be done. I believe the oil refiners and distributors will need to pay more attention to the kind of gasoline they distribute in say Michigan, which is subject to zero weather, or say in Death Valley, Cal., where the temperature reaches 115 deg. fahr.

S. M. UDALE[13]:—Regarding experience with airplanes, during the War there was pressure on the fuel tanks and therefore pressure on the gasoline nozzle itself. This refers to the ordinary war-type airplane; in those cases, we practically never heard of any trouble. I was responsible for the British Government carbureters at that time. With the complicated passages in modern carbureters, if any vapor exists it is inevitable that at some time it will cause hesitation; when taking off, that might be fatal.

T. S. KEMBLE[14]:—I presume that vapor lock may have aggravated certain airplane-engine troubles experienced in 1915, but we did not believe that they were caused by vapor lock. It might be interesting to know that we cured our difficulties by changing the mounting of the engine so that the gasoline line was subject to less vibration. In connection with the shaking of the bomb in a Reid apparatus to free the vapor, as already mentioned, it is notable that, in 1915, we did not change the fuel lines, the temperatures involved, or the gasoline; but, by changing the mounting of the engine so as to reduce the vibration of the gasoline lines, we eliminated the lock and secured satisfactory operation.

It is desirable to bear in mind that vibration of the gasoline line may constitute a source of lock largely or entirely independent of what is termed vapor lock.

Experience with Vapor Lock Cited

A. J. SCAIFE[15]:—Regarding the motorcoach and the motor-truck, we have had considerable vapor-lock trouble not only with the vacuum tank but also with the auto-pulse and the fuel pump. I believe this is because they are mounted under the hood in the hottest place. I have taken an auto-pulse out from under the hood, where it would fail because it was very close to

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[11] M.S.A.E.—Research associate professor of mechanical engineering, University of Arkansas, Fayetteville, Ark.

[12] Engineer, A. C. Spark Plug Co., Flint, Mich.

[13] Engineer, Holley Carburetor Co., Detroit.

[14] M.S.A.E.—Consulting engineer, St. Louis.

[15] M.S.A.E.—Consulting field engineer, White Motor Co., Cleveland.

the engine, placed it down on the frame next to the gasoline tank and pushed the gasoline up instead of pulling it up. We were operating in an air temperature of 100 deg. fahr. That made its operation satisfactory. There was no more of the "pulling dry" of which drivers were complaining. Another case is in connection with the fuel pump. We are all mounting our fuel pumps on the crankcase of the engine, and the crankcase temperatures are somewhat higher than the temperatures of the circulating water. We connect the pumps directly to the crankcase of the engine where they get all the heat in addition to outside temperatures of 100 to 115 deg. fahr. The temperature under the hood under the above conditions is about 200 deg. fahr., and we are trying to pump fuel that has an initial temperature of about 115 deg. fahr. Why not install the pump on the transmission or somewhere where it can be cooled, instead of placing it on the engine?

NEIL MACCOULL[16]:—Many otherwise fine cars have their performance spoiled by vapor lock, and something must be done about it. Two obvious ways exist for eliminating the trouble. The first one, and the one we are hearing most about, is to change the gasoline so that it will not vapor lock at the temperatures existing in those cars; the second is to reduce the temperatures existing in their fuel systems or to change the design of the fuel system.

A fact not yet brought out here is that, as the vapor-locking temperature of the gasoline is reduced, the difficulty of starting in cold weather is increased. It is clearly obvious that oil refiners will produce fuels which will give satisfactory performance in a majority of cars. They must; and, if the car designers leave their fuel systems as they are, the oil refiners will supply gasolines which will meet the requirements; but this will make it harder to start the engine in cold weather.

It seems to me logical to examine these systems and reduce the existing temperature as much as possible. Many cars are designed so that the gasoline and even the carbureter systems are subjected to entirely too much heat. They must have been designed in the days when the fear existed that every year would bring heavier and heavier gasoline. New refining methods have made it possible to bring out lighter gasoline, but this is causing much trouble. There is thus the choice between a gasoline less volatile at the light end, or, if that is not satisfactory to the customer, as I am sure it is not, the alternative is to reduce the vapor-locking tendency of the fuel system.

General Remarks on Fuel Systems

DR. H. C. DICKINSON[17]:—Concerning what constitutes a good fuel system, Dr. Bridgeman's analysis furnishes a foundation for some useful generalizing. In a fuel system designed so that the temperature at all points is below the normal bubble-point of the fuel, we deal with a straightforward system in hydrodynamics; that is, the flow of a simple liquid with no complications. But in a system in which the temperature at some point rises above the normal bubble-point of gasoline, we are dealing then with another type of general hydrodynamic system; namely, one in which a mixture composed of a liquid and a gas is required to be handled.

In various hydrodynamic problems it is not uncommon to deal with such systems; for example, where it is necessary to handle both a liquid and a gas. The obvious thing then is to provide for some means of separating the gas from the liquid and for getting the liquid out, alone, where we want it. In other words, some provision must be made for separating the two components. In a general way, that is the entire problem of handling fuel in a system which is subject to vapor lock, and it can be solved to a certain extent by the method ordinarily used for handling mixtures of liquid and vapor. If the drainage is in the right direction and if there is opportunity for the gas to escape at the right point, and if there is no opportunity for vapor to collect at the wrong points, then it is possible that a system may operate successfully even if the temperature does sometimes rise above the normal bubble-point of gasoline. That is not saying anything about the danger involved in vaporizing gasoline under the hood, or about the economic loss of boiling away gasoline without burning it; but, from a purely mechanical viewpoint, there is a solution of the problem.

CHAIRMAN JAMES:—In that connection, I have known of some cases in which, according to all the rules, cars should not operate; cases in which the rear tank was at a temperature of between 140 and 145 deg. fahr. on the road, and the temperature at the top of the fuel pump where it was discharging into the carbureter was approximately 180 deg. fahr. The car still operated, and a possible explanation is that, so long as the gas, which Dr. Dickinson mentioned as being formed and carried along with the liquid, is kept moving and acts somewhat like a stream of soda water or charged water, it will not hesitate long enough to collect in any one spot.

Recently, a complaint was made of trouble with a carbureter; it was said to be too hot and to be causing vapor lock. We tried using very light fuel, and then used very heavy fuel, but very little difference was evident. The trouble occurred when the carbureter was cold as well as when it was hot. In the course of the argument about it, the carbureter manufacturer operated a car with the gasoline boiling in the carbureter.

Much can be done in carbureter design to make the carbureter itself capable of handling a mixture of fuel and vapor in small bubbles. I bring this out because in some cases the car should not function but actually does function. I believe that the velocity at which the bubbles are carried with the liquid has something to do with it. Sometimes the fuel line is made too large in an endeavor to reduce the suction head and make the velocity such that vapor can collect.

Referring to Mr. MacCoull's point as to whether we shall have a good starting fuel or good vapor-lock fuels, the oil companies have met that comment by providing two kinds of fuel. Several years ago the American Petroleum Institute held a meeting in Los Angeles. The delegates were very much amused by the signs that were displayed on all gasoline stations, "Winter gasoline for sale here." If that is true in southern California, it must occur in other parts of the Country. I believe that the major difficulty due to vapor lock is in the summer, when the fuel is light.

Airplane and Other Experiences Related

W. LAURENCE LEPAGE[18]:—When associated with the operation of the New-York-to-Miami Air-Mail Route,

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[17] M.S.A.E.—Chief, heat and power division, Bureau of Standards, City of Washington.

[18] M.S.A.E.—Executive engineer, Kellet Aircraft Corp., Philadelphia.

which was very largely a night-flying proposition in extremes of high and low temperature, naturaline was used in our air-cooled engines, this being a gasoline which has a very low initial-point. We were continually warned by refiners of other gasolines that the engines were susceptible to difficulties due to vapor lock; but, so far as I could discover from a very definite effort to analyze the problem from that viewpoint, none of our difficulties ever could have been attributed to vapor lock.

Vapor-lock problems in automobiles have been mentioned here in such a way as to leave no doubt that the speaker regards vapor lock very seriously. Possibly there is something about fuel systems in automobiles in connection with which engineers could learn points from the practices of airplane fuel-system installations, although the problem is in no sense a similar one.

MR. UDALE:—In the development of our recent down-draft carbureter we were troubled with the bubbles that formed in the passages leading from the float chamber into the mixing chamber; but by reducing those passages to the simplest possible design and eliminating all the bends, as indicated in Fig. 19, we were able to solve the problem. It is a most serious question. The more complicated the passages are from the float chamber to the nozzle, the more likely it is that this difficulty will occur.

Suggestions for Obviating Vapor Lock

CHAIRMAN JAMES:—Everyone would welcome a simplification of the passages in carbureters. In one case of vapor lock, it was located in the fuel line. The line had been kinked, but as soon as the kink caused by the bump was straightened out, the fuel lock disappeared. This bears out Mr. Udale's comment on curves and abrupt changes of section in the carbureter nozzle.

J. B. HILL[19]:—It is doubtful that the vapor-lock problem might be solved by two gasolines. If only winter and summer were concerned, possibly it could be; but, experience is that vapor-lock trouble comes in the spring due to the sudden changes from hot to cold weather and vice versa. It may become very warm in April when we are normally running on a gasoline which is adapted to winter weather, but which is suddenly called upon to serve for both hot and cold weather. I emphasize Mr. MacCoull's point that the automobile designer must do something about it. Elimination of vapor lock and easy starting are diametrically opposed, so far as the fuel is concerned.

MR. SCAIFE:—Does trouble with vapor lock occur on vehicles having gasoline tanks mounted as on a Ford car, or can vapor lock of this kind be blamed on the carbureter? Is not the vapor-lock trouble due to the devices between the carbureter and the gasoline tank?

MR. BAUER:—Answering Mr. Scaife, we found in our work on gravity-tank systems that there would very seldom be heat enough present to cause vapor lock. We have never obtained a gasoline temperature of over 135 deg. fahr. in the carbureter bowl on a Ford car, which temperature is generally low enough to avoid vapor lock. At the same time, the gravity fuel-system usually has a tank temperature high enough so that there is a slight amount of distillation in the tank itself. I have never found a fuel in the Ford carbureter that was within 10 deg. of having a vapor-lock temperature.

MR. CLARK:—Another problem in the Ford installation has been overlooked, although Dr. Bridgeman mentioned it. A hydrostatic pressure exists which is usually higher than that which is present in other systems, and this tends to overcome the vapor lock in the fuel. The nozzles are under pressure, and not under vacuum.

CHARLES A. WINSLOW[20]:—Referring to some of our early experiences with vapor lock in marine-engine installations where we had fuel tanks located in various parts of the boat, and fuel lines running around shaft-logs, exhaust lines and the like, the problem generally resolved itself into making a U-tube out of the pipe line with the low point in the center, if possible, so that the gas bubbles could escape from both ends. Our trouble was generally eliminated if we did not allow the vapor to pocket between the tank and the carbureter.

Experiences with Fuels in Foreign Lands

E. J. GAY[21]:—In preparing a car for the Royal Automobile Club tests in London in 1929, it was able when equipped with a vacuum tank to travel three laps at top speed without stopping. When a pump under the dash was used, the car traveled six laps. We then installed the pump on the first cross-member in front of the gasoline tank and provided it with a metal shield to prevent breaking. The car was then able to operate throughout the required hour at top speed without stopping.

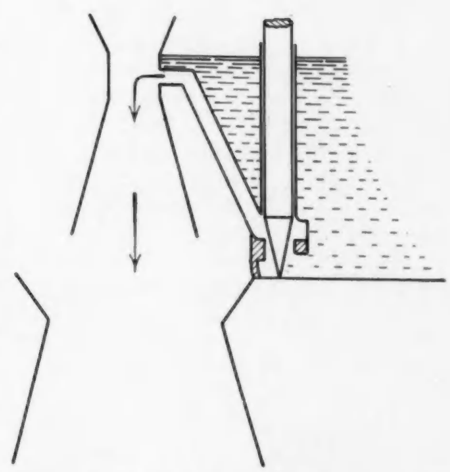

FIG. 19—CARBURETER DESIGN INDICATING HOW BUBBLES WERE ELIMINATED BY STRAIGHTENING THE PASSAGES

The gasoline in South Africa is of a better grade than we generally get here; but the temperatures there are high and we had a great deal of trouble to secure proper carburetion. I found it advisable to disconnect the heat-control systems entirely and put a solid asbestos-and-copper gasket between the hot-spot and the manifold joint. This often cured the carburetion troubles. I believe that too much heat is applied to the manifold and the carbureter sometimes.

MR. MACCOULL:—Mr. Gay mentions the "better grades" of gasoline available and used in South Africa. It is amusing that every attempt made during several years to make a "better gasoline"—by which we all assume a more volatile gasoline—has resulted in more trouble in modern cars.

MR. GAY:—That is true, we have more trouble with carburetion in the export countries that furnish us with good gasoline than we do at home. I have advanced the theory, to the engineers in the factory, that if they go back to the old simple carbureter on an ex-

[19] M.S.A.E.—Chief chemist, Atlantic Refining Co., Philadelphia.

[20] M.S.A.E.—Development engineer, Hercules Motors Corp., Canton, Ohio.

[21] Export service, Hupp Motor Car Corp., Detroit.

port job they will have less trouble than with the complicated carbureters equipped with fuel pumps and economizers to handle the gasolines that are sold in the United States.

Need for One or for Two Fuels?

DR. BRIDGEMAN:—The automobile engine must start and it must keep running. In other words, one fixes the minimum temperature and the other fixes the maximum, the range being about 140 deg. fahr. If we want the engine to start at zero fahrenheit, the fuel-line temperatures must be kept below 140 deg. fahr. to produce continuous running of the engine. If that can be done, then one gasoline will serve every purpose. If it cannot be done, then we may have to use more than one gasoline. But if the engine designers or the fuel-line designers will design or can design the fuel line so that the temperatures of the fuel in that system are kept below certain maximum temperatures, which are determined by the minimum temperatures at which the engine is to start, then one fuel or one type of fuel will serve satisfactorily. If that cannot be done, then it may be necessary to use more than one fuel.

HARRY F. HUF[22]:—Vapor-lock troubles are not general with a large number of cars. Many cars use vacuum tanks and never have trouble; likewise, many that use fuel pumps never have trouble. In some cars the carbureter is so placed that, while the type of feed may reduce the tendency to vapor lock, it would never eliminate it from volatile gasoline. Vapor locking is very often accelerated in winter by using shutters which give summer temperatures under the hood after the engine is started; but winter-grade gasoline is needed for starting. I think design is the pertinent factor.

MR. BABITCH:—It is possible to have vapor lock with gravity feed to the carbureter, as instanced by a car that was run with a vacuum tank and a gas strainer at Phoenix, Ariz. After a certain length of time the engine seemed to slow down. The best speed then possible with the car was 35 m.p.h., whereas it usually would run at 68 to 70 m.p.h. By persistently running at 35 m.p.h., a point was reached where the car would stop. The vacuum tank was investigated immediately by disconnecting the line to the carbureter, and plenty of gasoline was found in the tank. Only one conclusion could be drawn; it was that the bubbles started to form in the line leading from the vacuum tank to the carbureter. The bubbles were pushing upward and there was not enough gravity force to overcome the bubbles; naturally, the carbureter starved itself.

Correction of Vapor-Lock Troubles

Our experience in correcting vapor-lock troubles was that, if the line is isolated from the exhaust muffler, and if an air space of approximately 1/4 in. is provided between the channel and the line itself, there will seldom be trouble with vapor lock. If the gas reaching the carbureter is below a temperature of 145 deg. fahr., little trouble will be experienced if the gas moves all the time. On the other hand, if the engine slows down and heat is allowed to accumulate in the gas lines, some, but not very serious, trouble might be experienced. With a standard gasoline having an initial-distillation point of say 100 deg. fahr., no trouble whatever will be experienced if the gasoline temperature on entering the carbureter does not exceed 125 deg. fahr.

CHAIRMAN JAMES:—There is one more or less effective safety valve in the normal carbureter line; it is the float bowl itself. Some help can be obtained there by having an adequate vent from the float bowl. When operating in hot weather, considerable vapor that has formed in the float bowl is forced out through the vent valve. This eases the conditions so that the jets do not have so much to do. In some cases, that is made more difficult by a small vent for the float bowl; but when the vent is sufficiently large and free, little trouble is experienced.

FREDERICK G. WHITTINGTON[23]:—Another item that has a bearing on this question of vapor lock, I believe, is the tendency of the car manufacturer to use feed pipes of very small size. Citing an instance of a few years ago on a car of prominent make, using a vacuum fuel-feed system, there were certain periods when fuel flow from the vacuum tank to the carbureter was completely stopped. Upon investigation, it was found that the car maker had, on his own initiative, reduced the size of the feed pipe from the rear tank to the vacuum tank to such an extent that a serious restriction was imposed. This resulted in a built-up vacuum within the vacuum tank itself, which nearly equalled the manifold vacuum, thus holding the atmospheric valve closed and preventing the delivery of fuel from the vacuum tank to the carbureter. A similar condition may exist in fuel pumps.

The more we restrict the supply pipe, the more we build up the vacuum within the fuel pump itself and, with this increased vacuum condition, we naturally aggravate a serious vapor condition which certainly must be taken into consideration. We must do all we can to avoid restriction of the fuel-supply lines.

Amorphous Sulphur Caused Trouble

C. G. WILLIAMS[24]:—Vapor lock, so-called, may have some very interesting side issues. One which I have experienced several times within the last three years is that, when driving in Illinois, the engine began to suck and the car immediately lost headway, soon coming to a stop. I opened up the gasoline line at the vacuum tank and found no gasoline. I tried blowing through the feed pipe and, after many trials, succeeded in clearing the line. I unscrewed the plug in the bottom of the gasoline tank at the connection to the supply line to draw off gasoline for the initial supply in the vacuum tank, and drew off about 1 pt.

As I was pouring this into the vacuum tank, I saw two small globules of yellowish color rolling around in the gasoline at the bottom of the can. I retained these and tried to get one between my thumb and forefinger. I succeeded in breaking up the globules into smaller ones and retained some amount of this substance on my thumb and finger. The action of this substance was almost instantaneous, being at least as rapid as the evaporation of the gasoline. It was so adhesive that the fingers could not be separated until dipped in gasoline. This stopping up of the gasoline line occurred three times while driving 128 miles. At Davenport, Iowa, I was told that it was caused by vapor lock, as the day had been very hot. My statement that it was a definite substance and not gas that sealed up the supply line did

(Concluded on p. 114)

[22] Jun. S.A.E.—Senior engineer in charge of automotive laboratory, Atlantic Refining Co., Philadelphia.

[23] M.S.A.E.—Evanston, Ill.

[24] M.S.A.E.—Chief engineer, Green Bay Barker Machine & Tool Works, Green Bay, Wis.

Bodily Steadiness—A Riding-Comfort Index

Discussion of Dr. F. A. Moss's Summer Meeting Paper[1]

In view of the following discussion, the Riding-Comfort Research Subcommittee, at a luncheon meeting following the Body Session at the Summer Meeting, voted approval of Mr. James's suggestion that drawings of the wabblemeter which has proved most successful be made available to persons wishing to make industrial application of the instrument. In furtherance of the plan, R. W. Brown, Chairman of the Committee, volunteered to make up the necessary drawings.

It is generally felt that the fact that the instruments are still very crude merely accentuates the remarkably consistent results which Dr. Moss has obtained. Moreover, the development of the instruments has been unusually rapid.

As is pointed out in the discussion, the work was started only a year and a half ago without any preconceived ideas of how the discomfort incurred by riding would ultimately be measured. Certainly no one at that time thought of the wabblemeter as a solution of this difficult problem of measurement, yet the results reported in Dr. Moss's 1930 Summer Meeting paper showed a definite tendency for an individual's efficiency of performance on the wabblemeters to fall off with driving. Tests of the taxicab drivers in particular seem to show a correlation between distance driven and amount of falling off; and there seems to be a definite, positive correlation between the vibrations of the automobile as recorded by the Brown accelerometer and the amount of fatigue or falling off in performance of the subjects on the wabblemeters.

At least one industrial application of the wabblemeter has been made for measuring the relative amounts of fatigue acquired by workers in various production processes, making it possible to choose the most economical operation method as regards conserving human energy.

The Committee heartily endorsed the continuance of the program as outlined and pledged complete cooperation in endeavoring to raise the necessary funds to meet the budget for the second half of the current year.

E. P. WARNER[2]:—I tried to express my general views of Dr. Moss's researches at the meeting in Detroit where he presented his progress report[3]. They are certainly of absolutely fundamental importance. Those who have been active in the promotion of the work of the Subcommittee group on riding comfort have, I think, been unanimous in their disappointment and surprise that so little active interest has been displayed on the part of the engineers who have not been directly engaged in the work of that group and on the part of the industry as a whole.

Since the paper was presented at Detroit there has, I hope, been some improvement in that respect. Those who attended the meeting in January will recall the rather ambitious program that was set forth at that time, and will remember that this instrumentation, this development of means of measuring riding comfort or the effect of the lack thereof, so that we need not depend upon the subjective determination and the individual impression of the man who takes a ride in the car, is only a beginning; it is only the development of a means to an end.

I trust that everybody who has sat through the reading of one of these papers and profited directly by it and taken part in the discussion that followed upon the reading will make himself a missionary to spread the news of the importance (I am sure you all recognize the importance) of making it possible to carry on, on a liberal scale and with assured support for a good number of years to come. This is not an undertaking that can be finished and expressed completely in one or two papers. It is going to go on for an almost indefinite period, and certainly the results will become more and more interesting for at least a couple of years yet. There will be more and more papers to present, provided the industry rallies to the support of Dr. Moss, of the riding-comfort group, and the previous speakers and others who are engaged in kindred fundamental work in the same field.

Many Small Contributions Needed

B. J. LEMON[4]:—We must have funds to carry on this riding-comfort research. Contributions were made last year, I think, by 12 interested companies. We want to continue the work, and other companies should be just as interested in it as are the original contributors. I think we have got to give support to this research in a financial way, not by large contributions but a large number of small contributions, so that we can spread the idea abroad and continue the work. In a year or

[1] See S.A.E. JOURNAL, June, 1930, p. 804. Dr. Moss is head of the department of psychology, George Washington University, City of Washington.

[2] M.S.A.E.—Editor of *Aviation*, McGraw-Hill Publishing Co., New York.

[3] See S.A.E. JOURNAL, April, 1930, p. 513.

[4] M.S.A.E.—Field engineer, United States Rubber Co., Detroit.

two the industry can apply these results to the machines in a way, I think, that is going to be of real benefit.

TORE FRANZEN[5]:—We have had very little success in soliciting funds from car manufacturers. So far we have seemed to find great interest among the vendors or makers of parts. This year we had only one car manufacturer respond. If there are any car engineers here, please carry that message home to your respective companies.

Suggests Furnishing Wabblemeter Drawings

WILLIAM S. JAMES[6]:—I believe it will not only further the work, but will further the collection of money to carry it on, if as soon as possible plans or drawings are made for at least a close approximation of what Dr. Moss thinks is the most satisfactory wabblemeter, these drawings to be distributed to a number of the motor-car manufacturers so that each manufacturer may have the opportunity to build a wabblemeter and test its use in his plant.

Last year's contributor, when approached again, will say, "We gave a little money last year. What have we to show for it?" I believe it would be much easier for us to bring the necessary pressure to bear if we had a machine. Even though it is not perfect, I believe we could say, "We have something to show for it, and it is giving us some help."

I think the progress Dr. Moss has made is quite remarkable. It is my feeling that the work would go ahead much more rapidly if we could make one of the wabblemeters generally available.

R. W. BROWN[7]:—I watched the development of this project from its early infancy and I believe I can state with some justification that it is very seldom that an undertaking of this nature has been shaped up so consistently and so usefully as has this. Any number of phases of this work are already far ahead of the application that can be made. For instance, the various accelerometers that have been developed assuredly are not perfect, but they are useful; they will give information that can be applied in a practical way.

I think Mr. James's suggestion is a very sensible one. In projects of this nature I feel that the Committee is prone to lay out a definite program and be so much interested in carrying it out that they forget to stop by the wayside and get into service what has been developed to a useful point.

I can say frankly that in my own experience the instruments which have been more or less a by-product of the fundamental job are appreciably ahead of the industry at the present time, and that they can be applied in a useful and practical manner. If that is a stepping-stone to what is required to finance the future of this project, I suggest that we all take whatever means may be available to use as such.

Results Remarkably Consistent

C. B. VEAL[8]:—The most remarkable features of the progress of this work, to me, have been, as Dr. Moss mentioned, the consistency of results with crude apparatus and the sureness, apparently, with which he has hit upon the wabblemeter as an instrument to measure riding-quality. I think none of us had any idea two years ago that this was the way to measure riding comfort. We were considering accelerometers, and were discovering that accelerometers did not tell the whole story. We did know what the car was doing, but we didn't know what that had to do with riding-qualities. We could not tell by a subject's answer whether or not he had a good ride. These instruments have been developed without any preconceived notions of their final form. The work thus far has been real research of a fundamental character, and, when we consider that it has been a sort of first trial, the results appear most extraordinarily consistent. We noticed today that, while there were a few variations in the results, the tendencies are almost continually uniform.

LOWELL H. BROWN[9]:—I am not as familiar with this work as I should be. What is the financing problem that you are talking about?

MR. FRANZEN:—It is required to raise $5,000 for this year's operation of Dr. Moss's research. Dr. Moss is generously donating his own time, for which the Society should be very grateful. The Society as a whole, the Council, has backed this project. If we should not be able to raise money as fast as it is spent, the Society will see to it that this work goes on. I do not think that it will be necessary for the Council to appropriate money, and such a procedure is not desirable, since it would soon drain the funds of our Society.

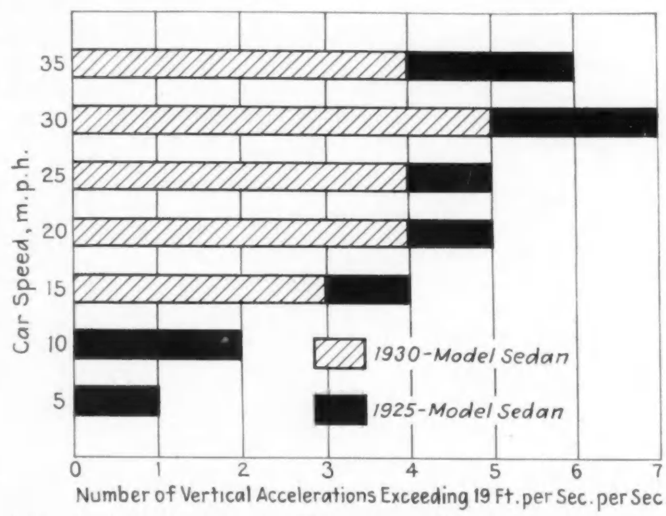

FIG. 1—COMPARISON OF NUMBER OF VERTICAL ACCELERATIONS EXCEEDING 19 FT. PER SEC. PER SEC. OF A 1925 AND A 1930-MODEL SEDAN AT VARIOUS SPEEDS

Recorded by a Firestone Accelerometer When Each Car Passed Over a Ramp 2 Ft. Long, 2½ In. High in the Middle, with a 1-Ft. Incline Approaching and Leaving the Middle

Tests That Correlate with Moss Data

MERRITT L. FOX[10]:—Dr. Moss's research in Washington to determine the relative amount of fatigue produced by riding in different types of automobile gives us a means to determine the type of motion which causes the greatest fatigue. This work has given me an exceptional opportunity to compare the measurements of vertical acceleration with those of angular acceleration in the two cars he used, and to correlate the values of both

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[5] M.S.A.E.—Research engineer, Chrysler Corp., Highland Park, Mich.

[6] M.S.A.E.—Research engineer, Studebaker Corp., South Bend, Ind.

[7] M.S.A.E.—In charge of engineering laboratories, Firestone Tire & Rubber Co., Akron, Ohio.

[8] M.S.A.E.—Research manager, Society of Automotive Engineers, New York City.

[9] Weymann American Body Co., Indianapolis.

[10] M.S.A.E.—Manager of research, Houde Engineering Corp., Buffalo.

angular and vertical acceleration with the relative fatigue, as shown by the students, resulting from riding in these cars.

Measurements of vertical acceleration were made using a single-element Firestone accelerometer, placed on the floor between the feet of a passenger sitting in the rear seat. The vibration element was adjusted with a field strength such that the figures on the recorder represent the number of times a vertical acceleration of 19 ft. per sec. per sec. has been reached or exceeded. In making measurements of the angular acceleration, the gyro-accelerometer was used. It has been found that the continuous record produced by this instrument is too difficult to evaluate on account of its great length, as it produces 20 ft. of record per minute.

To overcome this difficulty, comparisons were made between the two cars by driving them over a ramp at different speeds and comparing the results obtained. The method used was much the same as that reported in a paper[11] I presented at the 1929 Summer Meeting, in which it was shown that the maximum value of angular acceleration occurred at the speed which gave the greatest discomfort to the passenger.

[11] See S.A.E. JOURNAL, October, 1929, p. 358.

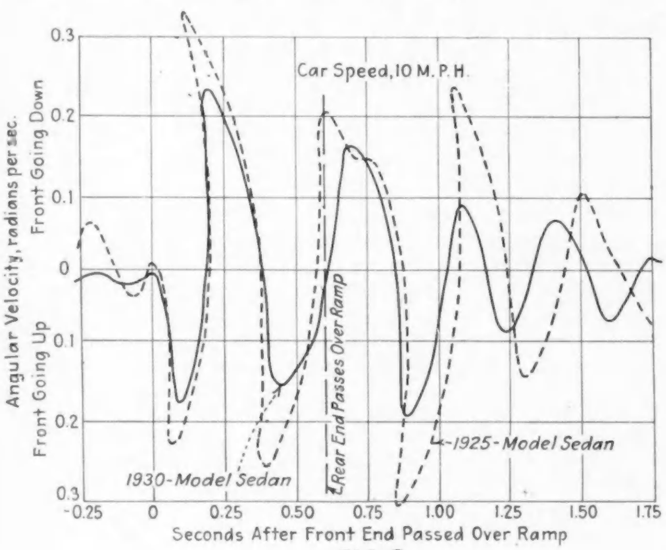


FIG. 2

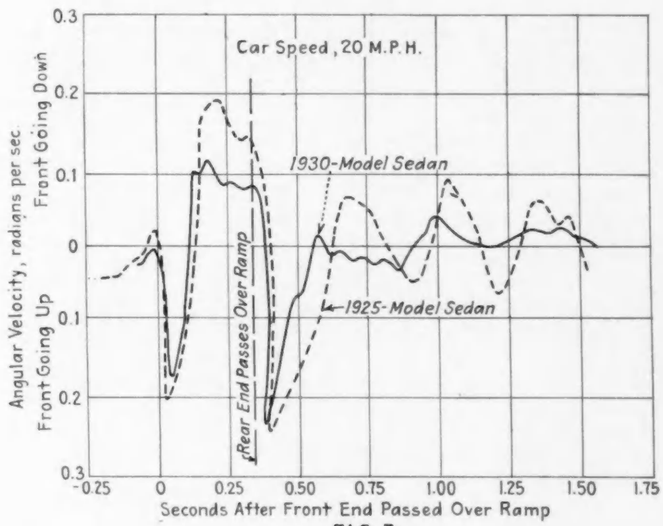


FIG. 3

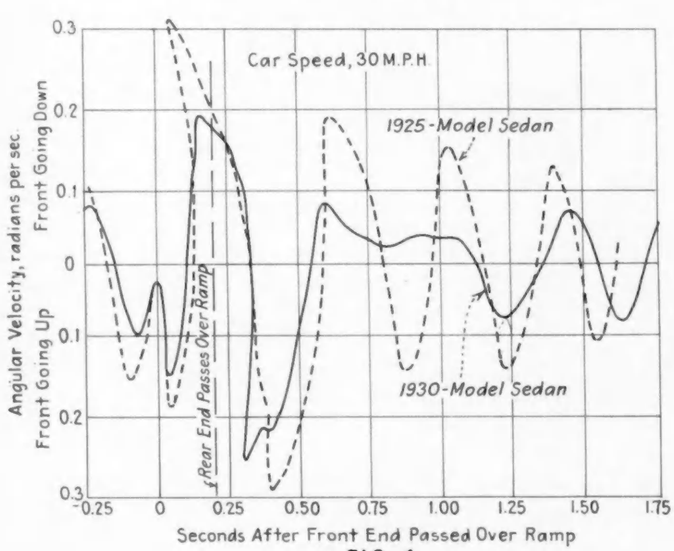


FIG. 4

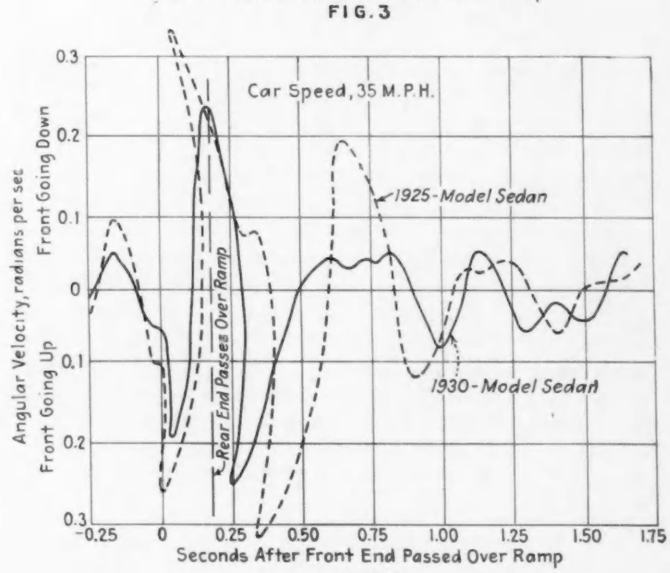


FIG. 5

COMPARISON OF ANGULAR VELOCITY OF A 1925 AND A 1930-MODEL SEDAN AT VARIOUS SPEEDS

Recorded by a Gyro-Accelerometer. The Angular Acceleration Is Shown by the Slope of the Record; the More Steeply the Line Slopes, Especially as It Crosses the Zero Line, the Higher Is the Angular Acceleration

FIG. 2—AT 10 M.P.H. THE ANGULAR VELOCITY IN THE 1925 MODEL IS MUCH HIGHER THAN IN THE 1930 MODEL

FIG. 3—AT 20 M.P.H. THE ANGLE MADE BY THE 1930 MODEL WAS SMOOTHED OUT QUICKLY AND THE VIBRATION OF THE OLDER MODEL KEPT ON CONSIDERABLY BEYOND THE 1½ SEC. SHOWN ON THE CHART

FIG. 4—AT 30 M.P.H. THE EFFECT OF THE CHANGES IN THE NEW MODEL IS STILL MORE EXAGGERATED, THE OLDER CAR HOLDING OUT ITS ANGLE VERY MUCH MORE

FIG. 5—AT 35 M.P.H. THE VIBRATION WAS SMOOTHED OUT MUCH QUICKER IN THE 1930 THAN IN THE 1925 MODEL, WHICH CORRELATES WITH THE DATA ON FATIGUE GIVEN BY DR. MOSS

The tests in the City of Washington were made by driving each car over a ramp 2 ft. wide, sloping from ½ in. at the edges to 2½ inches at the middle. Fig. 1 shows the number of times a vertical acceleration exceeded 19 ft. per sec. per sec. on the Firestone accelerometer when driving the cars over the ramp. It will be noticed that the 1925-model sedan had a larger number of counts at all speeds and that the 1930-model sedan had no counts below a speed of 15 m.p.h. In making a long trip with this type of instrument it was found that very few counts registered when driving over smooth paving, the counts being registered when the car passed other cars, when it was off the side of the paving, or when it passed over crossings.

Figs. 2 to 5 were made from tracings of the gyro-accelerometer record taken when the car passed over the ramp at different speeds. The full line represents the 1930 model and the broken line the 1925 model. On these records, angular motion with the front end of the car going upward is recorded above the center or zero line, and angular velocity with the front end going down is recorded above this line. The record is made by operating the paper at constant speed, so the horizontal scale is a measure of time taken for each change in angular velocity.

It will be seen that, if the height of the record from the zero line is a measure of velocity and the horizontal distance is a measure of time, the slope of the lines is a measure of angular acceleration. The more steeply the line slopes, especially as it crosses the zero line, the higher is the angular acceleration. The record being made from left to right, the slope of the record line away from the zero line indicates angular acceleration and the slope of the line as it approaches the zero line indicates angular retardation; thus a rapid acceleration indicates a "throw" and a rapid retardation represents a "spank."

In Figs. 2 to 5 it will be noticed that the angular velocity is much lower in the 1930 model, this being especially noticeable at higher speeds. At 30 and 35 m.p.h., as shown in Figs. 4 and 5, the angular reaction had been practically ironed out 0.6 sec. after the front end of the car had passed over the ramp. However, at these speeds, the acceleration, due to the rear wheels passing over the ramp, gave a little more "throw" and a little less "spank" than did the earlier car, the angular velocity, however, not being so high in the 1930 car.

It is apparent that this analysis of the angular motions in the two cars correlates closely with the data Dr. Moss has given us on the fatigue produced from riding in these cars, and that we have additional evidence that physical fatigue is closely related to accelerations.

Properties of Gasolines with Reference to Vapor Lock

(Concluded from p. 110)

not convince the service-station attendant. I had the same trouble with my car for months.

After a study of the manufacture of gasoline, I decided that the stoppage was caused by an ingredient that was suspended in the gasoline and which was, under certain conditions, deposited in the tank. My opinion was that this was some derivative of the sulphur either inherent in the petroleum or that remained from the action of the sulphur used in the distillation of gasoline. During 1928, a gasoline congress was held in London at which considerable discussion was offered regarding a similar substance that had been found in gasoline and which was determined by chemists as a derivative of the sulphur used in the distillation of the gasoline. I tried to produce the substance chemically from sulphur, but had no success. However, by working backward from the substance collected, I was able to obtain minute particles of sulphur and in that way determined that the substance was a form of amorphous sulphur held in suspension in the gasoline and which, under certain conditions, deposited on the sides of the gasoline tank; the action of the gas when the automobile was running washed the precipitate off the tank and allowed it to collect as a ball of heavy glutinous substance in the lowest portion of the tank, from whence it was drawn into the gasoline-supply line by the suction of the vacuum tank and caused a complete stoppage of the supply line until blown out. I have never experienced "vapor lock," as such, and am somewhat inclined to question whether the trouble may not have been caused by the same substance that I have just now described in detail.

Production Engineering

Steel Airplane Construction

British Fabrication and Use of Rolled Alloy Steels Described by W. R. Jones

OBSERVATIONS on the manufacture of metal aircraft structures, gained from a visit to Great Britain which he had previously made, were reported at a recent meeting of the Northwest Section by W. R. Jones. Mr. Jones, who is a member of the Society, designed the mail planes of the Boeing Airplane Co. in his capacity as project engineer of that company. He is now president of the Willis-Jones Machinery Co. The following remarks, mostly in regard to the fabrication and application of high-strength steel sections, are taken from Mr. Jones' talk.

The use of high-strength steels in airplane construction is one of the most interesting things to be observed in Great Britain. There is a constant battle as to the relative advantages and disadvantages of aluminum alloys and high-strength steel alloys, just as the relative merits of monoplanes and biplanes are being argued. Each material has advantages and disadvantages, but alloy-steel construction has reached a high state of perfection in Great Britain; I know of nothing in this Country that approaches their type of construction.

Steels Are Described by Proof Test

Steels of this sort are produced in England in a form which is suitable for the aircraft industry as it is not in this Country. The usual strength of this steel is what is designated as 60-ton proof. This indicates that, when the steel is subjected to a stress of 60 long tons or about 134,000 lb. per sq. in., the elongation curve will deviate from a straight line to the extent of 1 per cent. The method of classifying steel by its proof stress, which has been standardized in Great Britain, seems to be a very logical method; stating the ultimate strength gives no indication of the elongation or deviation from a straight line stress curve that can be expected.

While the 60-ton steel that is common is a very high grade of material, very thin sheets are being produced in an alloy that develops a 90-ton proof stress, slightly over 200,000 lb. per sq. in. This is the type of steel used in the construction of the British airship R1H1, which is made almost entirely from alloy steel. When treated to realize this high strength, the metal must be capable of being bent over a radius equal to three times the thickness of the sheet.

The alloy generally used is a nickel-chromium alloy. This alloy is used in this Country, but has been found very difficult to work. Such difficulties seem to have been overcome in England, and the material is being used with great success. It is being used by several manufacturers for wing beams, struts, ribs and other parts.

Light Structural Sections Are Rolled

Sections of great rigidity for spar flanges or spar webs are rolled in huge machines from strips up to about 120 ft. long and possibly 6 to 12 in. wide. A series of rolls is built into the machine, so formed and arranged that the various corrugations and curves that are desired are rolled into the strip as it proceeds, all the time under tension. The steel also passes through an electrically heated die, and it is treated with a gas flame to prevent deterioration of the surface. It has a nicely polished appearance when it emerges from the die.

The steels are air hardening; but many of them require some tempering, which is done by passing the strip through a water-cooled die as it emerges from the machine. The result is a section that is perfectly formed, true and clean and heat-treated without distortion, ready for assembly into the spar.

Machines Are Used in Assembling

Machines have also been made for assembling the various units of the spar automatically. The rolled webs are passed through this machine, which will drill the holes at one point and insert and head the rivets at another point. After completion, the entire spar and rib assembly is dipped in enamel and baked. Very little rusting is encountered in service after this treatment.

Steel construction is thought by some to be expensive, but it is surprising to see what can be done by means of ingenious designs in assembling fixtures and jigs.

This high-strength steel is also rolled into lock-seam tubes with walls as thin as 0.018 in. Uniform wall thickness is thus secured, and the lack of concentricity resulting from the seam is taken into account in structural design.

Rib construction is much the same as in American practice only that many manufacturers are using high-strength steel for this purpose. Channel sections always are made with the edges turned over for stiffness. I believe that ribs made from such channel sections are quite as efficient and much better than those which we make, with our tendency to adhere to closed sections such as seamless tubes. Many manufacturers who use steel spars make the ribs from duralumin, because the section of the steel rib becomes so fragile; nevertheless, many steel ribs are being used.

Sheet-steel fittings that are exposed to the elements are now being made from stainless steel, to avoid corrosion. This material is difficult to fabricate, so it is being used only for flat fittings.

Machined Fittings Made in Quantity

Fuselages usually are made from either steel or aluminum-alloy tubes having machined fittings which are bolted or riveted in place. The British claim to be able to produce joints having machined fittings for the same cost at which we can produce welded or brazed joints having stamped steel fittings. The probable explanation involves the lower cost of labor and standardization of fittings which make possible a certain amount of volume production. Practice is more or less standardized as to diameter of tubes, cup joints for attaching struts, and machined sleeves for joints.

Ingenious machines have been developed to replace the hand riveting which is such an expensive item. I saw one very ingenious machine which will insert a rivet from the outside and form heads on both the inside and outside at the same time in a very small tube. Our usual procedure is to "fish in" the rivet end from the end of the tube and hand rivet it from the outside. This takes much time and is not always successful.

Transportation Engineering

Fleet Maintenance Analyzed

Questionnaires Summarized by E. C. Wood Give Data on Pacific Coast Practices

NEED for greater economy in fleet operation has confronted the fleet operator with the problem of whether it is cheaper to maintain his own repair shop or have his work done outside under contract. According to a comparatively recent report made by E. C. Wood, a prominent member of the Northern California Section, at San Francisco, who analyzed replies to questionnaires sent to Pacific Coast fleet operators, several operators there send not only repair work of a minor nature but even major overhauls to outside shops, and other fleet operators in general are giving considerable thought to finding a satisfactory solution of this economic problem.

Important Factors Stated

Mr. Wood states in part that several important factors have a direct bearing on reaching a decision as to which of the two systems is the more economical. The managements of various firms and corporations are demanding greater economy from the fleet superintendent, and they do not care which method is followed so long as the work is done at the lowest possible cost.

One of the important factors is the staff overhead. The personnel is governed by the number of vehicles in the fleet and the amount of work it is proposed to do on them. It is astounding how greatly the number of men on the staff varies in different fleets. Obviously, the number of men needed cannot be determined by a formula. Fleet operators' requirements differ widely in details. For instance, one operator might decide to send out his minor repair-work, while another would equip his shop to deal with every phase of maintenance, including painting, upholstering and body work. Hence it is very difficult to determine just how many men are needed to maintain a given number of vehicles. A standardized fleet of one or two makes of vehicle could be maintained with fewer men for a given number of vehicles than could a fleet composed of various makes, the reason being obvious.

Another factor is the capital investment required to bring old vehicles more or less uptodate. The status of the vehicles on the books should not be overlooked. It is important to know just how much money should be spent on a vehicle, whether the maintenance work is done in the operator's own shop or in an outside shop. If the vehicle has been entirely depreciated and is carried on the books without further depreciation charges, probably a moderate sum can be spent on its maintenance without bringing the cost of its operation, repairs and overhead above the average.

Various Methods Used

Some companies maintain their fleets by annual overhauls. They report that it is cheaper to have their work done outside, including body repairs and painting, when they can assure the outside shop of a certain volume of work. In many cases it has been found that it pays to have electrical work attended to by specialists in outside shops on the flat-rate basis.

Analysis has been made of information on tire, electrical, and upholstery repairs. Comparing the fleet operator's shop-time, plus his overhead, with invoices received for this work from outside shops, it was found just as cheap, and in some instances cheaper, to send such work outside. Those who maintain their fleets by unit replacement have their replacement units rebuilt and repaired by the vehicle manufacturer or dealer. The man in charge of a fleet maintained in this way is relying on a load factor of 100 per cent of his equipment and, to obtain this service from his equipment, must have a certain amount of capital invested in spare parts to assure continuity of service.

It is true that a fleet operator who carries this stock can get along with a shop for only minor repairs and rely on the service department of the vehicle maker or dealer to do the major work. Reports on this kind of operation indicate that he effects a saving. It is evident that he can get along to a certain extent with unskilled labor, because he can have his engines, transmissions, and differentials picked up at his shop, the precision work required in complete overhauls done outside, and the unit parts returned ready to be installed in the chassis.

Another point brought out by the operators is that they are able to determine the cost of the work beforehand, as it is based on the flat rates of the service department; also, a cost that he eliminates is that of training mechanics. It will be realized that the fleet operator who is called upon to economize thinks first of the personnel as being the department in which to reduce expenses most easily.

Investment in Shop Equipment

Another cost mentioned in connection with unit-replacement maintenance is capital investment in shop equipment. A fleet operator who has a shop fully equipped for crankshaft grinding, cylinder reboring and the like, rebuilds the units in his own shop. He feels that he can do better work, and in some instances such operators report and prove that they have better continuity of service, fewer breakdowns on the road, and the advantage of being able to give important service when required. Moreover, they have been able to get longer life out of the vehicles, primarily because of the inspection service.

In all cases of large fleets maintained by the operator's own shop, it has been found that this was an organization in which a close inspection-system was followed and the superintendents or foremen were able to educate the men so that they became competent. These are especially important points in the case of a mixed fleet. The educated fleet-mechanic is found to be superior in every respect to the public-garage mechanic. He seems to have a better appreciation of the cost of repairing and keeping the vehicles in service; which he acquires primarily, it is felt, from living with the equipment from day to day.

A fleet superintendent once told me that he would not hire a man who had worked in a public garage because these men are, in a sense, semi-mechanics; through no fault of their own, they resort to a hit-or-miss system of handling repairs, have no consideration for the labor or material expended on a job, and do not have the opportunity to become thoroughly familiar with any one make of vehicle. The workman in a public garage may work on a carbureter adjustment and then repair a punctured tire; and the main objective is to get the job done in a hurry.

One operator of a fleet argues that, so long as he has the garage problems

of storage, servicing, continuity of service, tires, oiling, greasing, and filling the gasoline tanks of his vehicles, he may as well maintain his equipment on the stitch-in-time method, since minor repairs bear a direct relation to major repairs. With a fully equipped shop and an educated shop-force, he should be able to do repair work and maintain his equipment at a lower cost than by sending work outside and paying someone else a profit on the work.

Questionnaire Replies Summarized

Some idea of the trend of fleet-maintenance methods on the Pacific Coast is given by the following summaries of and quotations from replies received to a questionnaire on this subject.

FLEET NO. 1

The company operates its own shops primarily for maintenance. Overhaul is cared for largely by a reliable service-department of the makers of the vehicles. A very close inspection-system, including servicing and greasing, is maintained. One mechanic is employed, he merely reporting to the superintendent the mechanical conditions of the equipment. Contracts are made with outside filling stations for gasoline and oil. A tire foreman takes care of the tires. Upholstery and painting work is contracted for with an outside shop. Whether it would be cheaper for the company to maintain its own shop on a major-overhaul basis is a question. Getting results is the all-important consideration.

FLEET NO. 2

This fleet operator feels that the stitch-in-time method is the one to follow. He employs traveling mechanics who service 95 per cent of the vehicles. These men follow an established itinerary, care for minor repairs, and render reports on the condition of the vehicles and on repairs that have been made. As the drivers are required to be proficient, the traveling mechanics teach them how to drive, driving being incidental to their duties as salesmen.

Major repair-work is sent out and is checked over very closely by the traveling mechanics against the specifications in the bids. The work done is then checked against time, and material is itemized on invoices when received. As a result, it is necessary merely to have a garage for storage purposes.

FLEET NO. 3

The unit-replacement system is used exclusively, and the operator finds that better results are secured by this method. He is able to keep the vehicles in service, and the facts prove this to be the most economical system yet tried. Greasing, oiling, refueling and similar servicing is done in his own garages. Throughout the territory are located small shops in which minor repair-work is done. No regular overhaul-period is set, and when a unit is reported in need of overhauling, it is sent into the shop for repairs. In some cases a replacement unit is sent to the vehicle in the field, where the exchange is made, and the replaced unit is returned for overhaul.

The units cared for by the replacement system include engines, transmissions, and differentials. Painting, upholstery work and tire repairing are sent out. The sending of repairs outside has been tried; but poor workmanship, inability to get service when wanted and unnecessary delay in performing the work resulted in a decision to return to the old system, under which it is not necessary to carry spare equipment.

FLEET NO. 4

In operating and maintaining the fleet, the sales department's organization is followed as to personnel and geographical segregation. The company is organized into 16 territorial districts, 12 of which have completely equipped garages capable of caring for general-overhaul work. In the four other districts the maintenance and overhaul work is done either in adjoining districts or by outside concerns. Each district is charged with the responsibility of maintaining and operating the vehicles within the district in accordance with standards of maintenance and mechanical practices issued by the office of the automotive department in Los Angeles. The district automotive personnel consists of an equipment man, who is responsible for the vehicles within the district; a shop foreman; shop mechanics; and traveling mechanics, who report to the equipment man.

Mechanical maintenance of the vehicles is accomplished in the following manner:

"The fundamentals of our system for handling mechanical repair-work on our fleet are to clear all trouble as reported by the drivers on the trouble tickets and to defer major overhauls by means of periodic inspections and tightening up. One thing we do not believe in is what we term a 'non-production inspection,' by which we mean an inspector going out, checking over a machine, doing no work, but turning in a report for someone else's scrutiny and possible action as to the mechanical defects reported.

"Our so-called inspections really constitute a complete going over and tuning up of the vehicle from radiator to taillight. In making these inspections, it frequently happens that the mechanic will find that there is potential trouble such as a cylinder or a crankshaft out-of-round, which, in time, will need attention. When this condition is discovered, the shop foreman is called in and it is decided whether the work is needed at once or whether the machine can be operated safely and economically for a further period without, say, removing the cylinder-block and regrinding both the cylinder and the crankshaft.

"The fundamental thought in all our work is to keep our vehicles operating efficiently and economically as long as possible and to defer major overhauls as long as possible. In connection with this phase of fleet operation, one problem we feel is worthy of considerable attention and study. It is physically possible to maintain any unit of equipment in 100 per cent condition; but this is obviously an unwise and uneconomical thing to attempt. The question to be solved is: In what condition is it proper to maintain a fleet or working units; that is, is 90, 80, 70, or what per cent, correct?

"We always have been firmly convinced that efficient and economical operation of any fleet is contingent entirely upon general inspection for tightening and tuning-up. The question is: How often shall this operation be performed? For a long time we were striving for an elapsed time of 30 days per vehicle between inspections, but our mechanical expense seemed to be running too high and, to economize, we decided to try lengthening the period between inspections. We made the elapsed time 60 days, and this resulted in marked economy of repair costs. The number of trouble tickets as turned in by the drivers increased somewhat, but not to anything like the extent of offsetting the economies effected by doubling the time between inspections.

"For a number of years we have been using with accuracy what we called our breakdown report. This is a report for the information of the shop foreman and his superiors of all calls from the field for mechanics. In the last analysis, transportation is successful only so long as the wheels keep rolling. We feel that the breakdown report will furnish as true an index as we know of to show the mechanical condition of our fleet. We are satisfied to maintain our own shop, based on mechanical condition and present cost.

FLEET NO. 5

"For a long time the unit-replacement system was used and a number of spare engines, transmissions and rear-ends were kept on hand. Engines and rear-ends were overhauled, these being installed when required. It seemed that the equipment was kept going continuously, and it was thought a good job was being done. But an analysis of the cost indicated that this was not the case and that it would be more economical to trade-in old equipment at the end of a certain life, doing only necessary work on the vehicles during their service life.

"This plan has been followed for about two years and a substantial saving has been effected. Since going to this system of making only minor repairs, close inspection, and replacing the equipment, it has not been necessary to use our shop. If there is a failure that warrants some major work, the job is sent out to some organization which has a good reputation and can do the work on the flat-rate basis. Our operation under this system is so successful that we feel we shall never return to our old plan of doing our own work.

FLEET NO. 6

"We do not hesitate to avail ourselves of the services of outside specialty shops when a commensurate saving in truck time or repair expense can be brought about. We refer particularly to cylinder-block regrinding, body-construction work, and even complete overhauling of various mechanical units. We operate on the principle that we

(*Concluded on p.* 119)

Standardization Progress

Changes in Division Reports

Made by the Standards Committee When Approving the Reports at the Summer Meeting

THE general results of the action taken by the Standards Committee on the reports of Divisions that were submitted to the Standards Committee Meeting at French Lick Springs on May 25, were given in the news report of the Summer Meeting in the June issue of the S.A.E. JOURNAL. Lack of space and time prevented reviewing in detail the action taken on the reports. Nineteen reports by eight Divisions of the Standards Committee were published in Section 2 of the May, 1930, issue of THE JOURNAL. When these reports were presented at the Standards Committee Meeting, a number of modifications were made and approved as here reported. All page references given refer to Section 2 of the May, 1930, issue of THE JOURNAL.

Aircraft Division

Besides the correction of one or two typographical errors, the following changes were made in the subjects reported:

PULLEYS, NON-METALLIC, ANTI-FRICTION

The tolerances for dimension *K* in the table at the top of p. 4 was changed to plus 0.000 minus 0.005.

PLAIN PULLEY SPACERS

In the table at the top of p. 4, the No. 10 bolt size was added for the smaller spacer and ¼-in. bolt size for the larger spacer.

TIE-RODS

The Division reported that the number of 90-deg. bends for both the streamline tie-rods given at the bottom of p. 4 and the internal tie-rods given at the top of p. 5 should be specified as follows:

For the streamline tie-rod, 13 bends were specified for the 2 smaller sizes, 11 bends for the next size, 9 bends for the next 4 sizes and 7 bends for the largest 2 sizes. The tolerance for the area of the 11,500-lb. strength tie-rod was changed to plus 0.0078 minus 0.0000 in. In the table of internal tie-rods, 11 bends were specified for the 2 smaller sizes, 9 bends for the next size and 7 bends for the largest 4 sizes. In the footnotes following both tables, the definite number of 90-deg. bends in the printed report was changed to read "the specified number of 90-deg. bends".

FLAT-HEAD PINS

The only change made in this report was from proposed S.A.E. Standard to proposed S.A.E. Recommended Practice.

AIRCRAFT ENGINE DIVISION

The reports beginning on p. 6, for the No. 50 Shaft End and the Propeller-Hub Cones and Nuts were withdrawn by the Aircraft Engine Division for further consideration and will later be reported again by the Division.

TAPER SHAFT-ENDS

This report was approved without modification.

Non-Ferrous Metals Division

The reports of this Division, beginning on p. 12, included four alloys with blank numbers. The following numbers were inserted in accordance with a report received from the Chairman of the Division just prior to the Standards Committee Meeting:

The alloy given at the bottom of the second column of p. 13 is identified as No. 26 and the three alloys on p. 14 are specified as Nos. 27, 28 and 29 in the order in which they are printed. The corresponding specification numbers were included in the general information on Protective Coatings for Aluminum, commencing on p. 15.

Reports Approved as Submitted

The report of the Ball and Roller-Bearings Division on the Separable (Open) Type Ball-Bearings and the three tables of Angular Contact Ball-Bearings, commencing on p. 7, were approved without modification, as was also the report of the Lighting Division on p. 11 and the Motorcoach and Motor-Truck Division on p. 12.

In presenting the report of the Electrical Equipment Division on Metric Spark-Plugs for Automobiles, the extensive consideration that had been given this report by the Subdivision of the Electrical Equipment Division, by the Division and by the Gasoline Engine Division of the Standards Committee was reviewed. A proposal was made that the report be modified by omitting the 9/16-in. skirt length on the ground that many spark-plugs are made to varying lengths and that the Society should not standardize beyond the end of the thread, as beyond that point the dimension for the skirt length is a matter of design to meet the individual conditions of various applications. After a protracted discussion, the report as submitted by the Division, was approved almost unanimously by those voting.

Additional Report Submitted

The following report for a revision and clarification of the S.A.E. Recommended Practice for Crankcase Lubricating-Oil Viscosity, p. 561 of the 1930 edition of the S.A.E. HANDBOOK, that had been passed at the meeting of the Lubricants Division held in Detroit on May 23, was reported to the Standards Committee. It was explained that this revision was submitted by the Division to close the gaps between the viscosity ranges for the several viscosity numbers and to include a further note to the effect that the standard numbers are strictly a viscosity classification and not an index to any of the other qualities of the oils.

Division Report Withdrawn

The report of the Screw-Threads Division, printed on p. 17 of Section 2 of the May, 1930, issue of THE JOURNAL, was withdrawn until the Division has had an opportunity to secure further information concerning patents. It was explained that, although the Society may adopt standards that may be affected by proprietary rights, the Division desires more time in which to secure full information about such rights that may have a bearing on this subject.

The Division plans to recommend this type of necked bolt for adoption as S.A.E. Standard, supplementing the present round unslotted-head bolts now published commencing on p. 366 of the 1930 Edition of the HANDBOOK.

Publication of Reports

The reports, as approved by the Standards Committee, were approved also by the Council of the Society and at the Business Session on the same day of the Summer Meeting and have been printed in HANDBOOK page form as the Supplement to the 1930 edition of the S.A.E. HANDBOOK. These supplements are being mailed to all members of the Society and may be obtained by others who desire them. The reports therein, together with the reports adopted by the Society at the Annual Meeting next January, will be incorporated in the 1931 issue of the S.A.E. HANDBOOK.

CRANKCASE LUBRICATING-OIL VISCOSITY NUMBERS

Viscosity Number	Viscosity Range Saybolt Universal, Sec. At 130 Deg. Fahr. Minimum	Maximum	At 210 Deg. Fahr. Minimum	Maximum
10	90	Less than 120		
20	120	Less than 185		
30	185	Less than 255		
40	255			Less than 75
50			75	Less than 105
60			105	Less than 125
70			125	Less than 150

In the case of prediluted oils, S.A.E. Viscosity Numbers by which the oils are classified shall be determined by the viscosity of the undiluted oils.
Wherever the S.A.E. Viscosity Numbers are used on prediluted oils, the container labels should show in some suitable manner that the S.A.E. Number applies to the undiluted oil.
The S.A.E. Numbers constitute a classification of crankcase lubricating oils in terms of viscosity only. Other factors of oil quality or character are not considered.

Transportation Engineering

(*Concluded from p. 117*)

are not primarily in the vehicle-repair business. Whenever it is possible to have work done more cheaply than we can do it ourselves, or even as cheaply, the work is sent out, the resources of our shops being conserved for work which we cannot farm-out. Before such work is let out, however, we satisfy ourselves fully as to the dependability of the outside shop bidding on the work.

"We do not use the flat-rate system in our repair shops, as we do not see wherein any distinct advantage would be gained, even if it were entirely practicable to use it. The flat-rate system, as we see it, is primarily for the purpose of letting the customer know, with a fair degree of accuracy, just what a certain job will cost him. That particular job is performed, and no other, though it might in the opinion of the shop be economical to do other work at the same time. We keep close watch on the work done outside, with close inspection by a competent mechanic, and invoices are checked for parts and labor against the report submitted by the mechanic. The work is charged to the job to check the total cost.

FLEET NO. 7

"At one time we used the complete-overhaul system and had a shop with machinery for almost every mechanical operation. But, due to the scattered locations of our cars, the repair bills were excessive and it was necessary to maintain several reserve cars Further, this system involved too much time in taking the cars to and from the shop. Then we found that, when a car was completely overhauled, so much was expected of it that, if any mechanical feature was not functioning as it should, we received severe complaint from the district to which the car was sent.

"'The cost per mile for the period after the overhauling was considerably higher than that for the earlier life of the car. We have since found that we can actually save money by disposing of the cars, regarding as depreciation the amount of money which would be spent in overhauling them. In this way we have obtained a much lower cost per mile. This does not apply to the heavier equipment, as our heavy trucks, which are expensive, are given more consideration regarding overhauling."

Motorboats Multiplying

Gerald White Tells Chicago Section How Outboards, Runabouts and Standardized Cruisers Are Advancing the Industry

MEETING at the Motor Mart, on the Navy Pier, the Chicago Section held a motorboat meeting, Tuesday, June 10, during the Motorboat Show. Gerald T. White, editor of *Motorboat*, presented a very interesting talk on many phases of motorboating and illustrated it with a number of statistical charts and photographs of motorboats. He also presented a motion picture showing Motorboat Activities of 1929, including pictures of outboard races and races between larger craft. Among the boats shown was one belonging to Gar, one of the most famous of the fifteen Wood brothers.

At the opening of the meeting, Treasurer E. W. Stewart gave a financial report which showed that the Section closed the year with a balance of $2,445, having operated for the year well within the budget while reaching a membership of 355, exactly the number estimated at the beginning of the year. Retiring Chairman D. P. Barnard then introduced the new officers of the Section, who were nominated by the Committee as reported in the S.A.E. JOURNAL for May, p. 643. Thereupon Mr. Stewart was promoted from Treasurer to Chairman, and assumed his new duties. The retiring Chairman then introduced a resolution concerning the death of Mr. Clarkson, which was adopted by a rising vote.

Boat Races Attract Throngs

Motorboating was said by Mr. White to be one of the greatest of sports in the number of people attracted to it. An unofficial count of the spectators on one day of a three-day meet in Cincinnati, a few years ago, was 125,000, and the attendance at a three-day regatta in Detroit was said to be 500,000 people. It is also a sport in which many classes of people can compete. Boys who have built boats in their own back yards sometimes compete in big regattas on an equal footing with millionaires; the back-yard outfit may not win, but it furnishes a lot of sport.

Motorboating for recreation also appeals to a large number of people and offers attractions that cannot be had in any other field of outdoor recreation. Motorboating is not hampered by speed laws or traffic delays.

As an industry, Mr. White believes that motorboating has grown faster than any other in the automotive field during the last two years. He also expressed a belief that further progress of aviation is limited, because aviation cannot appeal to the ordinary man and it does not seem reasonable to expect that many people will keep airplanes in their back yards with which to fly to their business.

Yacht clubs are located in New York at the foot of East 42nd Street, East 23rd Street and the Battery. Mr. White said that at least $1,000,000 worth of boats commute to these landings every morning in the summer. Many smaller boats are used daily for commuting on the Hudson.

Landing facilities now are inadequate to care for a large number of boats, but Mr. White visualizes a service that will take a runabout from the dock and anchor it alongside a station boat during the day.

GREY DAWN II—MR. WHITE'S AUXILIARY CRUISER

Motorboats by the Million

Further evidence of the industrial development of motorboating was cited in the paid attendance of the last New York Motorboat Show, which is said to have been greater than that of the Automobile Show that closed a few days earlier. Mr. White saw at least 150 people waiting in the rain for the doors to open on the second day of the Show, an hour before opening time.

Licensed motorboats in the Country total about 240,000, including only boats that are more than 16 ft. long and are operated in waters that are listed by the Government as navigable. Because other boats are not registered, accurate figures for motorboats are not available, as they are for automobiles. A close analysis of the industry is reported by Mr. White to indicate an approximate total of 1,500,000 in the Country, having a total value estimated at $1,500,000,000. The boat-building industry cannot be said to be in its infancy, but the building of standardized boats and the awakening of general public interest is in its infancy.

Mr. White mentioned a recent visit to the new plant of the Dodge Boat Co. in Newport News, Va. He reported that the plant is working 24 hr. and turning out 40 boats per day, with a total of 840 men on the payroll. The company plans to double the plant next fall, giving it a capacity of 10,000 boats during 1931, the range of prices being approximately $945 to $5,500. Several other plants in Detroit and in the Metropolitan area are comparable in size.

Quantity production, according to Mr. White, has not yet resulted in proportionate reductions in price, but what he said indicates that price reductions are possible in 1931.

One significance of this movement to members of the Society was said by Mr. White to be the opening of a new field for engineers. All of the plants building standardized boats employed engineers, who are called naval architects because it is a special branch of engineering. There are also opportunities in the manufacture of marine engines, as indicated by a single current order for 2500 engines, and in the design and sales of boat equipment and accessories, of which an immense variety is required for many different types of boat.

Metal boats have a great appeal to the engineer, visualized by Mr. White as exemplified by a tremendous press that will receive a plate of metal directly from the furnace. The operator will pull a lever; cachunk—boat! Realization of this vision awaits several things, one of them being an economical metal that will not corrode in salt water.

Slides shown by Mr. White included statistical charts indicating the consumption of fuel and oil in motorboats; depreciation—extending, by the way, over a 20-year period; the geographical distribution of boats; and the price ranges of different manufacturers.

GERALD TAYLOR WHITE

Views also were shown of standardized boats in the process of manufacture and of a variety of completed boats, among them one new design having the engine in the extreme stern driving the propeller through gears at its forward end.

Maps Do Not Show All Markets

D. P. Barnard expressed regret that the motion pictures of boat races which were shown could not be followed by motion pictures of the outboard races held at the 1929 Semi-Annual Meeting of the Society at Saranac Lake. He recommended a little experience with 8-ft. hulls, such as were used in that race, to make a man appreciate how heavenly his ordinary humdrum existence is. He also reported seeing a placard in a hotel in Wyoming announcing motorboat races in a neighboring town, far from any river or lake that is shown on a map. He found that the races were to be held in a small artificial reservoir.

Mr. Barnard also mentioned a lucrative motorboat taxi business on the Chicago river between a landing at the base of the Wrigley Building and the station of the Chicago and Northwestern Railroad, offering a saving in fare and in time because of avoiding traffic congestion in the streets.

Financing plans came up for discussion, and Mr. White said that financing is handled the same as for automobiles, with a down payment of about one-third. Some companies now have a scheme whereby the owner pays only during the boating season, because it is harder to make payments after the boat has been hauled out for the winter. In discussing operating experiences, Mr. White said that his own boat, which is a 37x14-ft. auxiliary cruiser, costs him about $300 per year. About one-half of this cost pays for winter care, including painting, scraping and caulking, and the rest goes for fuel and miscellaneous expenses during the five months in which the boat is used as a summer home.

Radical Cars Coming

"Bill" Stout Philosophizes and Makes Predictions at Detroit Section Gathering

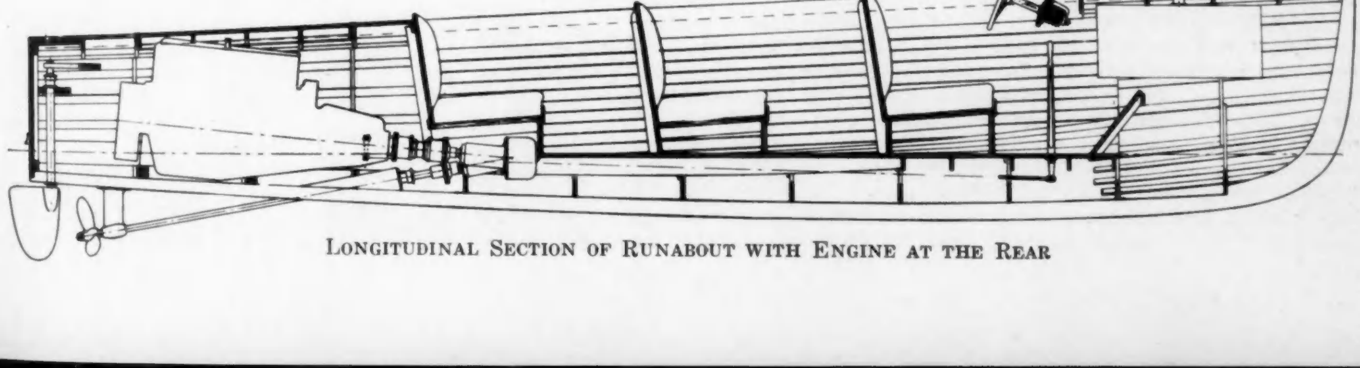
"WE are going to have radical cars. The industry is about ready for it. The buying public has changed tremendously in the last three years. I have heard the expression used, and I agree with it, that today the public is buying only two things in motor-cars: swank and transportation."

This quotation represents the theme of William B. Stout's address at the May 16 meeting of the Detroit Section, at which L. C. Hill presided as Chairman. He led up to predictions of the directions that developments may take by a philosophical disquisition on the evolution of ideas, the creation of industries and wealth, and the human tendency to follow precedent when developing a new means of transportation. He traced briefly the transition from the days of cut-and-try methods of individual hand work to the present era of machine production and said that if we start out now to create anything, we have to make a series of analyses based on all the facts that went before, and the analyses are rather definite. If the world's best locomotive designer were started on designing a fitting for an airplane landing-gear he would have to change his whole habit of thought and would spend many times as much time on the design before it was right as would a designer who had never even seen either a locomotive or an airplane, because he would have to forget so many things in his training as a locomotive designer in order to bring the part down to the light weight and accuracy required in the newer industry.

Design Body as a Structure

Although the airplane industry is an outgrowth of the automobile industry, it is giving back to the motor-car industry a number of ideas in accuracy of analysis, precision of work, and lightness of construction. Contrasting the airplane with the automobile, Mr. Stout said that the former is designed primarily as a structure, because we can compromise with aerodynamics but not with structure. "What good," he asked, "is an airplane that is twice as efficient aerodynamically if the wings come off the first time it goes up?" So millions of dollars have been spent in the last few years in the development of the lightest possible structures and getting them into the simplest possible form.

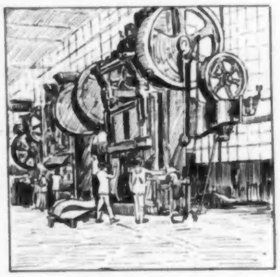
"Has anyone ever thought of designing a motor-car as a structure?" Answering his own question, the speaker said, "I think not, because he would not build them as they are now built if they were designed primarily as a structure. Between the front and



LONGITUDINAL SECTION OF RUNABOUT WITH ENGINE AT THE REAR

rear axles is mounted a closed body that is a deep truss, but, with all that strength, steel channels are used under the body. The first year the frames twist and the radiator dances, so the frames are strengthened. The next year the body cracks, so the body i strengthened; and the third year the frame trouble recurs, because all the stresses have been localized at one point."

Although the idea of building the whole body, including the hood, as a structure, and perhaps running a truss through it, has been thought of many times, said Mr. Stout, this was not practical years ago, because the body could not undergo painting and drying for several weeks and then be allowed to be scratched and soiled during the attaching of the various assemblies. But now, with nitrocellulose finishes, the problem should be simpler.



"If there is anything the industry does not want it is a radical car, because then everyone would have to work," remarked Mr. Stout. "It is entirely possible to build a motor-car, with the knowledge of engineering we have today, that will have twice the performance of the present car in everything except top speed. It can be built in half the weight, and will give greater comfort and hold the road better because of its lighter weight. We have paid little attention to unsprung weight and a lot of other things we all know we ought to have. The proof that the public is ready for radical things is that the only two radical big cars that have been brought out are pushing the others out of the door today."

With what has been learned in the last two years from the airplane, anything can be done with air-cooling that can be done with water-cooling, and with less weight, asserted the speaker. There is no reason why we should not make automobile engines today weighing 2 lb. per hp. and at no more cost than the present engines, considering the quantities produced.

Our public is not the same as it was a few years ago. Then it fought anything radical; now, anything that is not a novelty does not get attention.

Could Double the Body Space

"I think the public is entitled, in a motor-car, to the space it buys," continued Mr. Stout. "It buys a lot of space and then can use only half of it; the rest stands on the street for the taxpayer to pay for in parking space. By a little thought and redesigning, virtually all of that space can be given to the car owner. It is entirely feasible to give more room on a Ford wheelbase than is available now in the biggest cars." Space occupied by the running-boards, wheel housings and even the engine can be utilized for passenger space, because bodies are so low that the running-boards are not needed, the wheels so small that they can go under the seat, and the engines can be laid flat or put somewhere else, suggested Mr. Stout. The double-ended motorcoach is an example of what can be done. If the body is built as a truss between axles, the car can have twice the inside capacity, if it is wanted.

Weight Saving Would Reduce Cost

We can have any motor-car with more horsepower per pound than any present-day car and a total weight of not more than 1500 lb., and the acceleration will be away beyond any that we have now. "We take 12 passengers in one of our trimotor airplanes, which weigh literally about the same as a 16-cylinder car, and accelerate from zero to 80 m.p.h. in about 8 sec. Try that with your motor-car." There is no reason why such engineering cannot be applied to the motor-car, except the cost, according to Mr. Stout. When anything is built in quantity, the cost runs about a certain figure per pound; and if half the weight is saved in an automobile, there would certainly be a saving in cost.

Must Combine Art with Engineering

The latter part of the address, which was sprinkled liberally with the speaker's characteristically cryptic humor, was a chalk talk on art applied to the automobile. In conclusion he said:

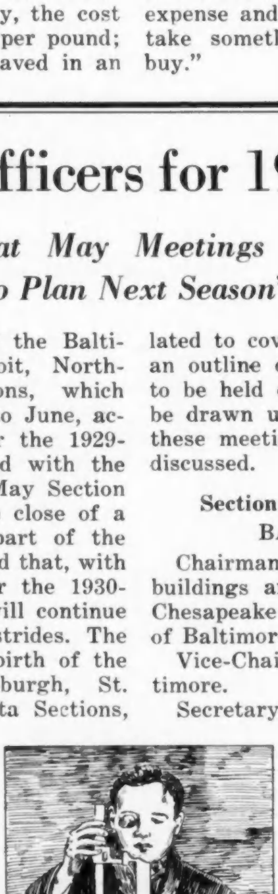
"I think we have come to a turning point in the engineering of motor-cars and that we are very close to a greater revision of design than we have ever seen. The sales departments wi'l be worried, because a radical design is very hard to produce with authority enough to get away with the first time it is tried, and unless the science of eye appeal goes in with the engineering, the product is going to fail. So those things must be correlated.

"We have learned that the fundamental is to build what the public wants and at the price at which it can buy it. I think the day is nearly past when we can sell motor-cars with brass bands or chorus girls. If we build what the public wants and will come in and take away from us, the sales department will have no problem except to write orders. I think we should put more of our effort and cost into quality of the car instead of an excess of sales expense and trying to make the public take something it would rather not buy."

Section Officers for 1930-1931

Personnel Elected at May Meetings Will Confer This Summer To Plan Next Season's Meetings

WITH the exception of the Baltimore, Chicago, Detroit, Northwest and Oregon Sections, which extended their meetings into June, activities of the Sections for the 1929-1930 season were concluded with the election of officers at the May Section meetings. This marked the close of a very active year on the part of the Sections, and it is anticipated that, with the following personnel for the 1930-1931 period, the Sections will continue in their rapid, progressive strides. The year just passed saw the birth of the Baltimore, Oregon, Pittsburgh, St. Louis, Syracuse and Wichita Sections, making a total of 21 S.A.E. Sections throughout the Country.



The new Governing Boards will meet during the summer months in a series of organization conferences in preparation for the coming year's work. Mailing lists will be brought up to date, budgets formulated to cover the year's expense, and an outline of the number of meetings to be held during the whole year will be drawn up, with tentative dates for these meetings and the subjects to be discussed.

Section Officers for 1930-1931

Baltimore Section

Chairman, G. O. Pooley, general buildings and supplies superintendent, Chesapeake & Potomac Telephone Co. of Baltimore City.

Vice-Chairman, Norton L. Dods, Baltimore.

Secretary, Joseph Bavett, superintendent of machinery, Yellow Cab Co., Baltimore.

Treasurer, Villor P. Williams, vice-president, consulting automotive engineer, George W. Davis Motor Car Co., Baltimore.

Buffalo Section

Chairman, William Edgar John, sales engi-

neering, Buffalo Gasolene Motor Co., Buffalo.

Vice-Chairman (Membership), J. R. Holmes, commercial engineer, Harrison Radiator Corp., Lockport, N. Y.

Vice-Chairman (Reception), E. A. Oehler, general factory manager, Stewart Motor Corp., Buffalo.

Vice-Chairman (Program), W. R. Gordon, Kenmore, N. Y.

Secretary, Marsden Ware, assistant engineer, Curtiss Aeroplane & Motor Co., Buffalo.

Treasurer, A. F. Carlson, chief draftsman, Pierce-Arrow Motor Car Co., Buffalo.

Canadian Section

Chairman, A. S. McArthur, general superintendent, Toronto Transportation Commission, Toronto.

Vice-Chairman, F. B. Averill, factory manager, Durant Motors of Canada, Ltd., Leaside, Canada.

Secretary, Warren Hastings, editor, manager, *Canadian Motorist*, Toronto.

Treasurer, W. E. Davis, assistant general manager, General Motors of Canada, Ltd., Oshawa, Canada.

Chicago Section

Chairman, Elliott W. Stewart, sales manager, in charge of sales and engineering, William D. Gibson Co., Chicago.

Vice-Chairman, Clarence A. Peirce, vice-president, in charge of production and engineering, Diamond T Motor Car Co., Chicago.

Secretary, Otto R. Schoenrock, director of engineering, Oliver Farm Equipment Co., Chicago.

Treasurer, C. J. Blakeslee, works manager, Walker Vehicle Co., Chicago.

Cleveland Section

Chairman, D. S. Cole, research engineer, Leece-Neville Co., Cleveland.

Vice-Chairman, W. E. England, Arrowhead Beach, Willoughby, Ohio.

Secretary, Hoy Stevens, assistant superintendent of maintenance, motorcoach department, Cleveland Railway Co., Cleveland.

Treasurer, F. Jehle, research engineer, White Motor Co., Cleveland.

Dayton Section

Chairman, Carl Kindl, chief engineer, Delco Remy Corp., Dayton, Ohio.

Vice-Chairman, F. W. Sampson, assistant chief engineer, Inland Mfg. Co., Dayton, Ohio.

Treasurer, A. N. Wilcox, president, Dayton Wire Wheel Co., Dayton, Ohio.

Secretary, G. W. Frank, mechanical engineer, powerplant, United States Army, Air Corps, Materiel Division, Wright Field, Dayton, Ohio.

Detroit Section

Chairman, P. J. Kent, chief electrical engineer, Chrysler Motors, Detroit.

Vice-Chairman, O. T. Kreusser, director, General Motors Proving Ground, Milford, Mich.

Secretary, D. E. Anderson, sales engineering, Bohn Aluminum & Brass Corp., Detroit.

Treasurer, F. W. Marschner, western sales manager, New Departure Mfg. Co., Detroit.

Chairman Body Division, H. R. Crecelius, body engineer, Lincoln Division, Ford Motor Co., Detroit.

Chairman Body Division Meetings Committee, A. J. Neerken, assistant chief engineer, Hupp Motor Car Corp., Detroit.

Chairman Aeronautic Division, Peter Altman, professor of aeronautical engineering, University of Detroit.

Chairman Aeronautic Division Meetings Committee, G. F. Vultee, chief engineer, Lockheed Aircraft Corp., Detroit Aircraft Corp., Detroit.

Chairman Entertainment, E. B. Reeser, assistant district manager, manufacturers sales, Willard Storage Battery Co., Detroit.

Indiana Section

Chairman, Louis Schwitzer, president, chief engineer, Schwitzer-Cummins Co., Indianapolis.

Vice-Chairman, Bert Dingley, vice-president, Stutz Motor Car Co. of America, Inc., Indianapolis.

Secretary, Harlow Hyde, executive secretary, Indianapolis Automobile Trade Association, Indianapolis.

Treasurer, C. A. Trask, equipment efficiency engineer, Rockwood Mfg. Co., Indianapolis.

Metropolitan Section

Chairman, Austin M. Wolf, automotive consulting engineer, Plainfield, N. J.

Vice-Chairman, John F. Creamer, president, Wheels, Inc., New York City.

Vice-Chairman for Aeronautics, Charles Froesch, sales engineer, Fokker Aircraft Corp. of America, Hasbrouck Heights, N. J.

Secretary, Grosvenor Hotchkiss, engineer, Western Union Telegraph Co., New York City.

Treasurer, Erwin H. Hamilton, assistant professor of automotive engineering, New York University, New York City.

Milwaukee Section

Chairman, J. R. Frantz, vice-president, LeRoi Co., Milwaukee.

Vice-Chairman, H. L. Debbink, superintendent, gasoline vehicles, Milwaukee Electric Railway & Light Co., Milwaukee.

Secretary, Prescott C. Ritchie, advertising manager, Waukesha Motor Co., Waukesha, Wis.

Treasurer, Eugene Bouton, industrial engineer, J. I. Case Co., Racine, Wis.

New England Section

Chairman, Albert Lodge, president, treasurer, Mohawk Chevrolet Co., Inc., Greenfield, Mass.

Vice-Chairman, L. W. Martin, Boston branch manager, United Motors Service, Inc., Boston.

Secretary, H. B. Hawk, resident manager, Valvoline Oil Co., Brookline, Mass.

Treasurer, V. J. Ogilvie, mechanical superintendent, Massachusetts Automobile Club, Boston.

Northwest Section

Chairman, D. F. Gilmore, manager, maintenance department, Sands Motor Co., Seattle, Wash.

Vice-Chairman, Walter Jones, president, Willis-Jones Machinery Co., Inc., Seattle, Wash.

Secretary, C. H. Bolin, general motor-vehicle supervisor, Pacific Telephone and Telegraph Co., Seattle, Wash.

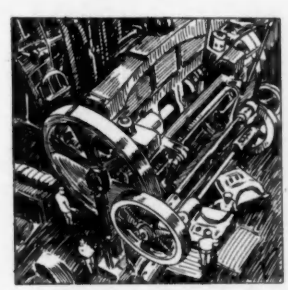
Treasurer, Charles Finn, resident agent, manager for Pacific northwest, John Finn Metal Works, Seattle, Wash.

Northern California Section

Chairman, E. H. Zeitfuchs, research engineer, refinery library, Standard Oil Co. of California, Richmond, Calif.

Vice-Chairman, Howard Baxter, president, owner, Howard Baxter Automotive Service, Oakland, Calif.

Vice-Chairman (East Bay), Carl Abell, sales engineer, Hall-Scott Motor Car Co., Berkeley, Calif.



Secretary, W. S. Crowell, claims adjuster, Home Accident Insurance Co., San Francisco.

Treasurer, C. J. Vogt, instructor, mechanical engineering, University of California, Berkeley, Calif.

Oregon Section

Chairman, H. W. Drake, superintendent of garage, Portland Gas & Coke Co., Portland.

Vice-Chairman, C. C. Humber, transportation superintendent, Longview Public Service Co., Longview, Wash.

Second Vice-Chairman, E. J. Blaser, manager, Factory Motor Car Co., Portland.

Third Vice-Chairman, F. G. Baender, head, department of mechanical engineering, State College, Corvallis, Ore.

Secretary, F. P. Myers, president, manager, engineer, Myers-Blackwell Co., Portland.

Treasurer, J. Vern Savage, superintendent, City of Portland Municipal Shop.

PHILADELPHIA SECTION

Chairman, Edmund B. Neil, director of research, *Automotive Industries*, Philadelphia.
Vice-Chairman, W. Laurence LePage, Kellett Aircraft Corp., Philadelphia.
Secretary, J. P. Stewart, automotive research engineer, Woodbury Heights, N. J.
Treasurer, L. E. Lighton, manager automotive manufacturers sales, Electric Storage Battery Co., Philadelphia.

PITTSBURGH SECTION

Chairman, John M. Orr, general manager, Equitable Auto Co., Pittsburgh.
Vice-Chairman, B. H. Eaton, motor-vehicle supervisor, Bell Telephone Co. of Pennsylvania, Pittsburgh.
Secretary, C. R. Noll, automotive lubrication engineer, Gulf Refining Co., Pittsburgh.
Treasurer, Murray Fahnestock, technical editor, *Ford Dealer and Service Field*, Pittsburgh.

SOUTHERN CALIFORNIA SECTION

Chairman, Fred C. Patton, assistant manager, Los Angeles Motorcoach Co.
Vice-Chairman, Wendell E. Mason, assistant professor of applied mathematics, University of California at Los Angeles.
Secretary, C. H. Jacobsen, service manager, Moreland Motor Truck Co., Los Angeles.
Treasurer, J. Jerome Canavan, manager, truck division, Thompson-De Jarnette Co., Los Angeles.

ST. LOUIS SECTION

Chairman, A. J. Mummert, secretary, chief engineer, McQuay-Norris Mfg. Co., St. Louis.
Vice-Chairman, Henderson Emanuel, foreman, assembly and test, Wright Aeronautical Corp. of Missouri, St. Louis.
Secretary, John Cox, automotive engineer, hydraulic brake division, Wagner Electric Corp., St. Louis.
Treasurer, V. C. Kloepper, engineer, Kloepper Co., St. Louis.

SYRACUSE SECTION

Chairman, E. S. Marks, chief engineer, H. H. Franklin Mfg. Co., Syracuse.
Vice-Chairman, Charles P. Grimes, sole owner, manager, Grimes Brake Engineering Service, Syracuse.
Secretary, L. W. Moulton, partner, Manufacturers Consulting Engineers, Syracuse.
Treasurer, M. R. Potter, service manager, Allen Cadillac Corp., Syracuse.

WASHINGTON SECTION

Chairman, C. S. Bruce, mechanical engineer, United States Bureau of Standards, City of Washington.
Vice-Chairman, C. S. Fliedner, technical advisor, engine section, Bureau of Aeronautics, Navy Department, City of Washington.
Secretary, John C. McCalmont, assistant aeronautical engineer, Bureau of Aeronautics, Navy Department, City of Washington.
Treasurer, E. M. Cornell, Eastern High School, City of Washington.

WICHITA SECTION

Chairman, A. W. Mooney, president, Mooney Aircraft Corp., Wichita, Kans.
Vice-Chairman, H. F. Brown, Travel Air Co., Wichita, Kans.
Secretary, W. W. McCutcheon, Stearman Aircraft Co., Wichita, Kans.
Treasurer, O. W. Wortman, Aircraft Steel Co., Wichita, Kans.

OHIO STATE UNIVERSITY STUDENT BRANCH

Chairman, Burritt G. Fleming.
Vice-Chairman, Frank T. Vorac.
Secretary-Treasurer, Brice A. Schmacher, Columbus, Ohio.

UNIVERSITY OF DETROIT STUDENT BRANCH

Chairman, Laurence R. Brady.
Vice-Chairman, Manuel Simms.
Secretary, Eugene T. Kelty, Detroit.
Treasurer, Stanley Skalski.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY STUDENT BRANCH

Chairman, Peter L. Loewe.
Vice-Chairman, Howard F. Jenkins.
Vice-Chairman for Aeronautics, John H. Minnick.
Secretary-Treasurer, Carrington Mason, Boston.

Dayton Summarizes Season

PAST-CHAIRMAN F. W. HECKERT, of the Dayton Section, reporting on the activities of the Section during the 1929-1930 season, states that eight monthly meetings were held and that the average attendance was 60, out of a total membership of 90. All the speakers were obtained from within the State. The activities were brought to a close with a meeting of the 1929-1930 Board of Governors on May 23.

Ohio State University Student-Branch Meetings

TWO meetings in April and one in May completed the 1929-1930 season of the Ohio State University Student Branch at Columbus.

On April 4, the Branch held a joint dinner in cooperation with the Columbus Chamber of Commerce in honor of Capt. Frank M. Hawks, who stopped in Columbus on his transcontinental glider flight. Following the dinner, Captain Hawks gave a talk on gliding and its possible utility. Details of the construction of the glider used by him were described by Walter Franklin, a member of Captain Hawks's party, and this was followed by general discussion.

The Engineering Problems of the Austin Car was the title of an address made by R. K. Havighorst, of the American Car Co., of Detroit, at a dinner meeting of the Branch on April 17, held in Pomerene Hall and attended by 32 members. After the talk the various features of the Austin baby car were the subject of a general discussion.

Election of officers for 1930-1931 was the main activity at a meeting held on May 28. The new officers elected are: Chairman, Burritt G. Fleming; Vice-Chairman, Frank T. Vorac; Secretary-Treasurer, Brice A. Schmacher.

Oregon Section Outing

THE summer meeting of the Oregon Section was scheduled for June 28, at Longview, Wash. Some of the members wanted to go from Portland to Longview by airplane, and Chairman H. W. Drake was endeavoring the week before the meeting to make arrangements for a cabin airplane to take as many as wanted to go that way. Another party of members was to go in a 1910-model White steamer, to be provided by Fred Dundee. This meeting concludes the meetings plans of the Section until September.

R. J. Minshall, senior designing engineer of the Boeing Aircraft Corp., was to give a paper on Present Tendencies of Military and Commercial Aircraft Design, and motion pictures of the equipment used and the process followed in the manufacture of seamless steel tubing were to be shown by a representative of the United States Steel Products Corp. The entertainment program was sponsored by the Texas Oil Co. and was in charge of Texas Lubricators.

University of Detroit Student-Branch Meeting

F. A. KUMMER, of the Packard Motor Car Co., was the speaker at the final meeting of the University of Detroit Student Branch for the season 1929-1930. His subject was the Packard Diesel aircraft engine, and he presented lantern slides showing the construction of the engine.

About 40 members attended the meeting, which was a very successful one. The election of officers for next year resulted as follows:

President—Laurance R. Brady
Vice-President—Manuel Simms
Secretary—Eugene T. Kelty
Treasurer—Stanley Skalski

How Industries Develop

AN industry is merely a mechanical means of producing wealth. Wealth is nothing but goods already produced. Money alone is not wealth. A country producing goods, and therefore employing labor, is creating wealth; and a country with an excess of wealth above that required for necessities begins to buy what we used to call luxuries. These luxuries were the things which, to the very sanctimonious of those days, used to be very sinful, because we were not supposed to have anything that was pleasant.

But as we progressed into a state of civilization in which we realized the value of industry, we began to find that the development of civilization came with the development of wealth, because with wealth came an increase of leisure, an opportunity of study, and a chance for advancement, not only in the industries and laboratories, but personally for the entire group of citizens. So we began to create industries and make luxuries; and, as we made more things and more money, there were more demands. After all, in spite of our early training, the very foundation of the growth of the world is selfishness. It is what we want that makes the world move; if we did not want anything, the world would not progress. Every want and every desire that we can put into the hearts of the citizens of our Country and others for the creation of something, all for the possession of something that creates a new industry, brings into being not only a new product but a new status of culture and advancement.

Think of the hundreds of industries that have come into being since the automobiles started. Think of how your own living at home has been revised by the mechanical additions to that home, each of which has produced an industry that has hired men in all branches. Every one of those things was based on facts and on some kind of research.

Only a little more than a generation ago, about 95 per cent of our population was comprised of workmen. Everyone was working directly; we had very few trained men to oversee and carry on the work of industries, because there were no industries. Things were expensive and inaccurate because they were hand made; and perhaps the only values that came from them were those of the art side. Virtually everything that was made by civilization before our generation, with the possible exception of music, was developed by a cut-and-try method.

But now if we start out to create anything, we have to go into a series of analyses based on all the facts that went before, and those analyses are rather definite; they are tied up in many ways with a man's very habits of living.

Each industry grew out of a former industry. When the railroads started, they had only wagons to go by. The first railroad coaches were stage coaches with flanged wheels. The entire development of the railroad car came as an outgrowth of the wagon. When the automobile came, we had railroad and highway vehicles to study. We started in with the horseless carriage, and the sad fact is that in many cases we have still kept many of the traditions of the buggy; it is a question whether we have not been going along for years doing obvious things instead of analyzing our problem.

We have recently developed the airplane industry from the automobile. Every industry that has come along has required just a little more accurate analysis than previous industries. It has required a little more accurate production, a little better finesse of sales, and a little better knowledge of psychology and those other things that enter into the world market, instead of the restricted market with which we originally started.

Whereas the airplane industry originally got from the automobile the airplane engine, the tires, the wheels and nearly every material it uses, it has now developed so many ideas that the automobile can use that the time seems to have come when a serious study should be made of those fundamentals to develop a type of road vehicle that is new and has an appeal.—From an address by William B. Stout before the Detroit Section in June.

Guggenheim Medal Awarded to Prandtl

DR. LUDWIG PRANDTL, of the University of Goettingen, Germany, is to be awarded the Daniel Guggenheim Gold Medal for 1930 for his pioneer and creative work in the theory of aerodynamics. This second award of the medal was voted to him by the Board of Award at a meeting of the Board in May. The medal was awarded for the first time to Orville Wright in April, 1929.

The Board of Award hopes that Dr. Prandtl will make a visit to this Country this year or early in 1931 and that the medal can be presented to him in person at some important meeting of the Society, which is one of the two American organizations from which members of the Daniel Guggenheim Medal Fund, Inc., are chosen, the other being the American Society of Mechanical Engineers. Five foreign organizations are also represented on the Board, one each in England, France, Germany, Italy and Japan. The American members of the Board, all of whom except Dr. William F. Durand are or were members of the Society (Mr. Sperry having died in June), were at the time of the award: William F. Durand, President Edward P. Warner, Elmer A. Sperry, Arthur Nutt, Howard E. Coffin, Paul G. Zimmerman, Capt. E. E. Aldrin and Capt. Emory E. Land.

The medal was founded in 1927 by the Daniel Guggenheim Fund for the Promotion of Aeronautics. At the annual meeting of the medal corporation in May the following officers were elected:

President, William B. Stout, representing the S.A.E.; vice-president, Capt. E. E. Aldrin; secretary and treasurer, Alfred D. Flinn, director of the Engineering Foundation; executive committee, Mr. Stout, Captain Aldrin and Edward P. Warner.

Dr. Prandtl is one of the world's most eminent authorities on aerodynamics and is well known as an investigator and teacher of the laws of mechanics, thermodynamics and the flow of fluids, particularly air and other gases.

Elmer A. Sperry

IN THE passing of Elmer Ambrose Sperry, the Society has lost one of its most distinguished members, an engineer and inventor who has contributed much to navigation by water and air. Mr. Sperry died in St. John's Hospital, Brooklyn, N. Y., June 16, after a period of failing health that culminated in an operation for gall-stones from which he failed to rally.

Born at Cortland, N. Y., Oct. 12, 1860, Mr. Sperry was educated at the State Normal School in that town and at Cornell University. He became interested in the automotive industry quite early, building 80 electric automobiles between 1896 and 1899 after having built electric traction locomotives and storage batteries. One of his early developments was an electric street-railway system that was sold to the General Electric Co.

The early development of aeronautics also engaged Mr. Sperry's interest. He was a member of the Society of Aeronautic Engineers at the time that organization was merged with the Society of Automobile Engineers and other organizations to form the present Society of Automotive Engineers, and he was made second vice-president of the S.A.E. representing aviation engineering in 1919. He was also a member of the House Committee of the Society from 1923 to 1927 inclusive.

Other societies to which Mr. Sperry belonged included the American Institute of Electrical Engineers and the American Electro-Chemical Society, of both of which he was a life member; the American Society of Mechanical Engineers, which he served as President in 1928; the American Chemical Society; the Society of Naval Architects and Marine Engineers; the American Physical Society; New York Electrical Society; the American Academy of Arts and Sciences; the National Aeronautic Association; the National Academy of Science and various clubs.

Survived by one daughter and two sons, Mr. Sperry never entirely recovered from the effects of the death of his son Lawrence, who was drowned in the English Channel about seven years ago in attempting a flight to the Continent. Lawrence Sperry had been a close associate and assistant of his father since boyhood. The death of Mrs. Sperry, in March of this year, brought on a serious illness that undoubtedly shortened Mr. Sperry's life.

Among the honorary bearers at Mr. Sperry's funeral, which was conducted by Dr. S. Parkes Cadman, at Plymouth Church, Brooklyn, N. Y., were Secretary of the Navy Adams and Thomas A. Edison. Secretary Adams' tribute included the statement that no other one American has contributed so much to our naval technical progress. Mr. Sperry had been a member of the Naval Consulting Board since 1915.

Many honors were awarded to Mr. Sperry, among them the Franklin Medal, the Collier Trophy and the John Fritz Medal, and he was decorated for navigational equipment by Czar Nicholas and received the Order of the Rising Sun from the Emperor of Japan. Mr. Sperry headed the American delegation to the World Engineering Congress in Tokio in 1929.

More than 400 patents were taken out by Mr. Sperry, between the time when, as a thirteen-year-old boy, he made a successful wooden water turbine and his recently developed Metal Mike, an automatic helmsman placed under the aviator's seat, that has been proved capable of maintaining an airplane on its set course without human assistance.

Gyroscopes have been the basis of many of the inventions for which Mr. Sperry has become famous. Among the most important of the devices which he developed from this mechanical toy are the gyro-compass and the gyroscopical stabilizer for boats. Another invention of great significance is an electrical device for detecting hidden flaws in steel. One of the developments of this device is an inspection car that is drawn over a railroad. Any flaw in one of the rails is indicated on a dial, and the location of the flaw is marked automatically by white paint on the track. At the age of 19, he perfected one of the earliest arc lights, and his name is well known also for powerful searchlights that are used for various purposes.

Coupling exceptional business ability with his inventive genius, Mr. Sperry founded numerous companies and disposed of many of them. One of them was the Sperry Gyroscope Co., of which he was president from 1910 to 1926 and chairman of the board since. This included a great manufacturing plant and experimental laboratory in Brooklyn, and was sold to the North American Aviation company in 1929. Sperry Products, Inc., was organized this year to continue the work of the Sperry Development Co., which was the experimental branch of the Sperry Gyroscope Corp. and the Sperry Rail Service Corp.

Mr. Sperry wrote a comprehensive paper on the subject of Aeronautical Navigation over Water, which was printed in the S.A.E. BULLETIN for December, 1916, p. 288, and TRANSACTIONS, 1917, Part I, p. 153.

Machinery for mining, a lighting system for motion-picture projection, electrochemical processes, a compound internal combustion engine and development of torpedos, mines and gun-fire control were among Mr. Sperry's inventions.

George E. Merryweather

ON JUNE 8, George Edmund Merryweather, another of the pioneers in the automobile industry and a prominent figure in the machine-tool industry, died in Cleveland.

Born in Cincinnati, in August, 1872, Mr. Merryweather was educated at the Cincinnati Technical School and received a degree of Bachelor of Science from the Massachusetts Institute of Technology in 1896. For five years he was employed by the Brown & Sharpe Mfg. Co., of Providence, R. I., following his graduation from M.I.T., and was that company's Paris representative in 1900, taking charge of its exhibit at the Paris Exposition. In the next year he became affiliated with the Overman Mfg. Co., of Chicopee Falls, Mass., and, after the consolidation of that company with the Locomobile Co. of America, at Bridgeport, Conn., was made assistant superintendent of the latter.

In 1904, with Edwin R. Motch, Mr. Merryweather organized the Motch & Merryweather Machinery Co., of which he became president and of which he remained head until his death.

Mr. Merryweather was elected to membership in the Society in 1908, and for the next six years was active in its affairs, having been a member of the Broaches Division of the Standards Committee from 1911 to 1915.

During the World War he was chief of the machine-tool section of the War Industries Board. He was a director of the Central United National Bank of Cleveland, the P. A. Geier Co. and the Davenport Machine Tool Co. of Rochester. He was a member of the Society of Mechanical Engineers, the Cleveland Chamber of Commerce, the Engineering Society of Cleveland, and of more than half a dozen social and athletic clubs in Cleveland, Detroit and Cincinnati.

James R. Jones

THE many friends and business associates of James R. Jones, general manager of the Bossert Corp., of Utica, N. Y., have learned with regret that he passed away recently.

Born in August, 1878, at Thorold, Ontario, Canada, Mr. Jones received a public school education there. He came to the United States in 1897, and was naturalized at Buffalo. For 15 years he was associated with the Crosby Co., of Buffalo, and after he left the employment of that company, he joined the Bossert Co. That his services were valued is attested by the fact that he served for 20 years as general manager of that company.

Mr. Jones was elected to Associate Membership in the Society in September, 1924.

Applicants Qualified

The following applicants have qualified for admission to the Society between May 10 and June 10, 1930. The various grades of membership are indicated by (M) Member; (A) Associate Member; (J) Junior; (Aff.) Affiliate; (S M) Service Member; (F M) Foreign Member.

ALLEE, HERBERT D. (M) production manager, Studebaker Corp. of Canada, Ltd., *Walkerville, Ont., Canada.*

ARRIGONI, FERDIE (A) president, Melrose Motors, Inc., 606-620 Bergen Avenue, *New York City.*

BANKS, K. C. (A) sales representative, American Car & Foundry Motors Co., 30 Church Street, New York City; (mail) 300 Westinghouse Building, *Pittsburgh.*

BERG, ALFRED GORDON (J) technical staff, Fairey Aviation Co., Hayes, Middlesex, England; (mail) care of Mr. Pullar, 73 Gunterstone Road, Barons Court, *London, West 14, England.*

BLACKSTOCK, GIBBS (A) 1106 Star Building, 80 King Street, West, *Toronto, Ont., Canada.*

BROEKHUYSEN, EGBERT (J) 174 Linden Street, *New Haven, Conn.*

CARRY, JAMES B. (A) superintendent of garage, auto transportation, Chestnut Farms Dairy, Inc., City of Washington; (mail) 38 Drummond Avenue, *Chevy Chase, Md.*

CASSIDY, JAMES F. (A) librarian, Standard Oil Co. of California, *Richmond, Calif.*

CHASKEL, E. F. (A) proprietor, 877 Massachusetts Avenue, *Indianapolis.*

CICALA, JOHN (J) student instructor, Cass Technical High School; student, College of the City of Detroit, Second Avenue and Vernor Highway, *Detroit;* (mail) 10222 Harper Avenue.

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Applicants for Membership

The applications for membership received between April 15 and June 15, 1930, are listed below. The members of the Society are urged to send any pertinent information with regard to those listed which the Council should have for consideration prior to their election. It is requested that such communications from members be sent promptly.

Adam, William Dudley, chief engineer, Willard Storage Battery Co. of Canada, *Toronto, Ont., Canada.*

Andre, William P., toolmaker and apprentice, Hudson Motor Co., *Royal Oak, Mich.*

Arnold, Fred J., experimental department, Waukesha Motor Co., *Waukesha, Wis.*

Babcock, Irving B., executive vice-president, General Motors Truck Corp., *Pontiac, Mich.*

Bailey, Donald J., lieutenant, Coast Artillery Corp., U. S. A., *City of Washington.*

Baker, Warren L., sales manager and advertising manager, Glenn L. Martin Co., *Baltimore.*

Ballin, Alfred Edward, president and general manager, McIntosh & Seymour Corp., *Auburn, N. Y.*

Barbour, Robert Yalding, structural engineer, Lord & Burnham Co., *Irvington, N. Y.*

Barclay, Stanton D., instructor, mechanical technology, Pratt Institute, *Brooklyn, N. Y.*

Beach, Russell S., lubricating engineer, Fisk Bros. Refining Co., *Detroit.*

Behrndt, Franklin J., tool draftsman, Fokker Aircraft Corp., *Hasbrouck Heights, N. J.*

Bennett, Ralph Stone, president, Champion Sheet Metal Co., Inc., *Cortland, N. Y.*

Bergius, Walker, managing director, The Bergius Co., Ltd., *Glasgow, Scotland.*

Bettys, Albert L., chief mechanic of motor maintenance shop, Varney Air Lines, *Portland, Ore.*

Biche, Jean H., engineer, French Air Ministry, Ritz Tower, *New York City.*

Bickell, J. P., registrar of motor vehicles, Ontario Government, Motor Vehicles Branch, *Toronto, Ont., Canada.*

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Biermann, Arnold E., junior mechanical engineer, National Advisory Committee for Aeronautics, *Hampton, Va.*

Billon, Marcel M., director general, Ste des Pistons Ideal & Segments Triplex, 14, Avenue Fontaine Argent, *Besancon, France.*

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Bjorckman, A., research engineer, Spontan Transmission Co., *Stockholm, Sweden.*

Blanchard, William P., Detroit manager, Sterling Clock Co., Inc., *Detroit.*

Bowen, William Spencer, president, Bowen Research Corp., *New York City.*

Bower, Donald L., student in mechanical engineering, Lehigh University, *Bethlehem, Pa.*

Brown, Warren G., draftsman, Caterpillar Tractor Co., *San Leandro, Calif.*

Brun, Andrew, draftsman, Sikorsky Aviation Co., *Stratford, Conn.*

Brunton, W. G., assistant chief, sales promotion department, Union Oil Co., *Los Angeles.*

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Cameron, Clifford S., aeronautical engineer, Boeing Airplane Co., *Seattle, Wash.*

Chapin, Albert J., sales engineer, Fageol Motors Co., *Los Angeles.*

Christensen, Martin P., service manager, Jacobsen Mfg. Co., *Racine, Wis.*

Colvin, Fred H., editor *American Machinist*, McGraw-Hill Publishing Co., *New York City.*

Conner, Andrew T., service manager, United Auto Sales Co., *Baltimore.*

Coulombe, France Bailey, laboratory engineer, International Harvester Co., *Fort Wayne, Ind.*

Crawford, Edwin Gail, sales engineer, Gramm Motors, Inc., *Lima, Ohio.*

Crawford, W. Frank, records, experimental department, Marmon Motor Car Co., *Indianapolis.*

Crumpler, Cyril A., service manager, Carter-Latter Motors, Ltd., *Winnipeg, Man., Canada.*

Davies, Frederick Detheridge, partner, J. Davies & Sons, *Rotorua, New Zealand.*

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Diescher, August P., co-partner, S. Diescher & Sons, *Pittsburgh.*

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Frohlin, Charles Robert, engineer, The Texas Co., *Bayonne, N. J.*

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Gates, Julius John, vice-president and treasurer, W. S. Purdy Co., Inc., *New York City.*

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Goldmann, David H., president, K. & G. Sales Co., *Baltimore.*

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Harris, Arnold T., engine designer, American LaFrance & Foamite Corp., *Elmira, N. Y.*

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ZERBI, TRANQUILLO, main technical director, F. I. A. T., *Turin, Italy.*

Notes and Reviews

AIRCRAFT

Effect of Variation of Chord and Span of Ailerons on Rolling and Yawing Moments at Several Angles of Pitch. By R. H. Heald, D. H. Strother, and B. H. Monish. Report No. 343. Published by the National Advisory Committee for Aeronautics, City of Washington, May, 1930; 29 pp., illustrated. [A-1]

This report presents the results of an extension to higher angles of attack of the investigation, described in Technical Report No. 298, of the rolling and yawing moments due to ailerons of various chords and spans on two airfoils having the Clark-Y and U. S. A.-27 wing sections.

The measurements were made at various angles of pitch but at zero angle of roll and yaw, the wing chord being set at an angle of + 4 deg. to the fuselage axis. In the case of the Clark-Y airfoil the measurements have been extended to a pitch angle of 40 deg., using ailerons of span equal to 67 per cent of the wing semispan and chord equal to 20 and 30 per cent of the wing chord. It is planned to later extend the investigation to hinge moments of the ailerons for the conditions covered in the rolling and yawing-moment tests.

Full-Scale Drag Tests on Various Parts of Fairchild (FC-2W2) Cabin Monoplane. By William H. Herrnstein, Jr. Technical Note No. 340; 14 pp., 17 figures. [A-1]

Calibration and Lag of a Friez-Type Cup Anemometer. By Robert M. Pinkerton. Technical Note No. 341; 8 pp., 10 figures. [A-1]

Experimental Research on the Friction of Pivots. By A. Jaquerod, L. Defossez, and H. Mügeli. Translated from *Journal Suisse d'Horlogerie et de Bijouterie*, Nos. 11 and 12, 1922, and Nos. 1, 2 and 3, 1923. Technical Memorandum No. 566; 54 pp., 15 figures. [A-1]

The Magnus Effect in Theory and in Reality. By F. Ahlborn. Translated from *Zeitschrift für Flugtechnik und Motorluftschiffahrt*, Dec. 28, 1929. Technical Memorandum No. 567; 40 pp., 17 figures. [A-1]

Contribution to the Theory of Propeller Vibrations. By F. Liebers. Translated from *Zeitschrift für Technische Physik*, Vol. X, 1929. Technical Memorandum No. 568; 23 pp., 5 figures. [A-1]

The foregoing Technical Notes and Technical Memoranda were issued during May by the National Advisory Committee for Aeronautics, City of Washington.

These items, which are prepared by the Research Department, give brief descriptions of technical books and articles on automotive subjects. As a general rule, no attempt is made to give an exhaustive review, the purpose being to indicate what of special interest to the automotive industry has been published.

The letters and numbers in brackets following the titles classify the articles into the following divisions and subdivisions: *Divisions*—A, Aircraft; B, Body; C, Chassis Parts; D, Education; E, Engines; F, Highways; G, Material; H, Miscellaneous; I, Motorboat; J, Motorcoach; K, Motor-Truck; L, Passenger Car; M, Tractor. *Subdivisions*—1, Design and Research; 2, Maintenance and Service; 3, Miscellaneous; 4, Operation; 5, Production; 6, Sales.

Proposed Method of Determining Design Tail Loads for Airplanes. By J. A. Roché. Air Corps Information Circular, Vol. VII, No. 650. Published by the Chief of the Air Corps, City of Washington, May 10, 1930; 9 pp., illustrated. [A-1]

The object of this report, as stated in the introduction, is to present a rational method for determining the values of design loads to be used for airplane horizontal tail-surfaces and fuselage tail structures. The report gives: (*a*) sample computations for the determination of tail loads, (*b*) tail-load curves and velocity diagrams for several Service airplanes of the Air Corps, (*c*) a ruling which is recommended as a substitute in the Handbook of Instructions for the present arbitrary tail-surface design loads and wing diving load-factors, (*d*) an appendix presenting a precise method for the computation of tail loads and justifying the use of the approximate method by which the tail-load curves given in the report were obtained.

The Analysis of the Sounds Emitted by Aircraft. By Juichi Obata, *Rigakuhakusi*, and Yahei Yosida. Report No. 59. Published by the Aeronautical Research Institute, Tokyo Imperial University, Japan, March, 1930; 185 pp., illustrated. [A-1]

The investigations described herein were undertaken to study the sounds emitted by aircraft in the hope of obtaining a new light on their nature. The sounds were recorded as accurately as possible by means of an electrical arrangement, and the analysis was carried out upon the records. The recording arrangement consisted of a band-microphone, seven-stage resistance-capacity-coupled amplifier and an oscillograph.

The aircraft used were a bomber, a chaser, a reconnaissance machine and a small dirigible. Straight-line flights and vertical turns were made. Experiments were also made upon an airplane on the ground with special reference to the directivity of the sound and to the influence of the number of revolutions of the engine on the nature of the sound.

The chief sources of the sound of an airplane are known to be the revolving airscrew and the engine exhaust. The pitches of the fundamentals of these sounds are given and the correspondence of the pitches of the recorded sounds to these values were studied in all cases. The authors conclude that, in general, the sounds of aircraft are of a very complex nature, overtones rather than the fundamentals being predominant in most cases. At long distances the greater part of the sound originates from the propeller, and it mainly consists of the fundamental and second harmonics, while at short distances the exhaust sound predominates.

Different airplanes equipped with the same kind of engine gave quite different records of sound. In calculating the pitch of the fundamental of the exhaust sound it was found that the number of cylinders per bank, instead of the total number of cylinders, should be used.

The Wright Brothers, Fathers of Flight. By John R. McMahon. Published by Little, Brown & Co., Boston, 1930; 308 pp., illustrated. Price, $2.50. [A-3]

The author gives the complete story of the Wright brothers, Wilbur and Orville, laying strong emphasis on the personal and human side. The story begins with their early childhood and is based on the unpublished letters and diaries of the two men, and on data obtained from Orville Wright and his family. The story of the trials and triumphs of these two inventors is told in a simple style from a sympathetic point of view.

Inflation of the Metalclad Airship, ZMC-2. By A. R. Carr and A. C. Good. Published in *Industrial and Engineering Chemistry*, March, 1930, p. 227. [A-5]

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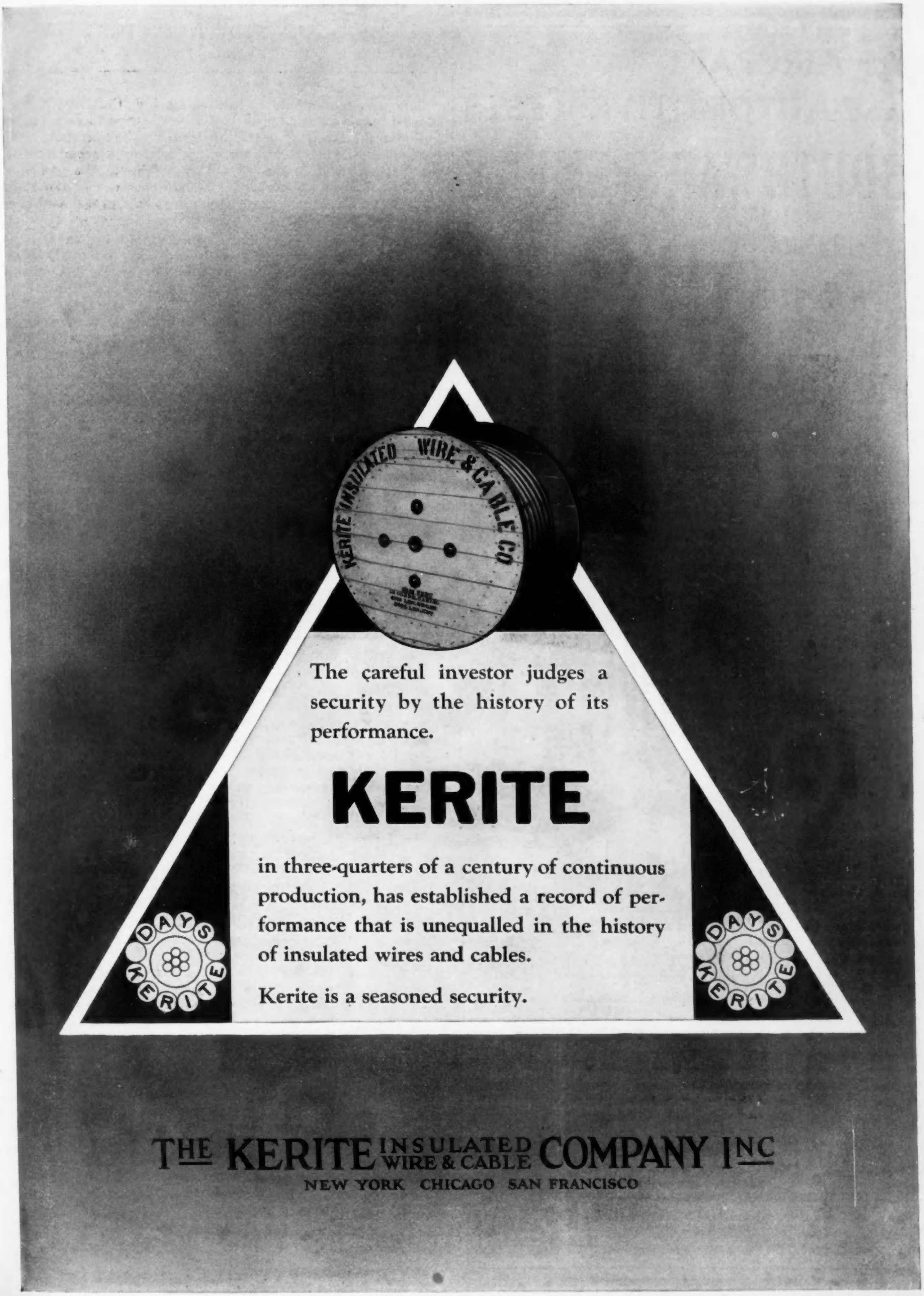
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The inflation of the metalclad airship, the ZMC-2, was carried out in two stages. In the first stage the air in the hull was displaced by carbon dioxide. In the second stage, the carbon dioxide was displaced by helium. Carbon dioxide was separated from the helium by scrubbing the gas in a caustic tower and the purified helium returned to the ship. Thus a purity of more than 92 per cent helium was obtained in the gas-filled hull.

Although the helium has been diffused outward at a rate of about 100 cu. ft. per 24-hr. day, no appreciable quantity of air has entered through the metal wall of the hull, which would cause a decrease in the lift of the ship.

The capacity of the ship, 200,000 cu. ft., makes it too small for commercial purposes, but its performance and characteristics prove the feasibility of similar construction for larger commercial units, thus making it a distinct contribution to lighter-than-air construction.

Ameliorations Possibles des Vues de l'Avions Classique Actuel. Published in *L'Aeronautique*, April, 1930, p. 117. **[A-1]**

The purpose of this article is to initiate and encourage discussion on the means by which the pilot's outlook from the conventional modern airplane can be improved. First, the visibility requisites in military maneuvers and the difficulty of filling them, which were so emphatically placed before aeronautic engineers and the general public during the World War, are recalled. Then the effect of different wing and engine designs and positions on obstructing or enlarging the pilot's view is shown, by discussion, photographs and schematic drawings. Recommendations are then made as to the arrangements thought most favorable.

However, according to the author of the second section of the article, an appropriate form of fuselage, an adjustable seat and an in-line inverted engine are only palliatives. A solution of the problem is to be found only in a radical departure from current design. An example is given of such a radical design, conceived for airplanes to be operated from an aircraft carrier. Among the secondary advantages claimed for it are lighter weight, greater comfort, diminution of engine noise, greater security against fire, an increase in maneuverability at take-off and low speeds, and a simplification of construction.

CHASSIS PARTS

Measurements Made of the Power Loss and Efficiency of a Motor Lorry Gearbox. By J. H. Hyde and F. Aughtie. Paper presented before the Institution of Automobile Engineers, London, England, April 1, 1930. [C-1]

The tests described in this paper were conducted with a view to ascertaining the sources of power loss in a transmission and indicating possible means of improving the design.

The authors explain that, although the transmission tested was of old design, having been constructed in 1912, differences between it and modern transmissions are only of detail or size, and are not of a fundamental nature.

The experiments comprise two series: (*a*) tests on the direct drive and lowest reduction-ratio gears at loads up to the normal full load, carried out with the object of separating the various contributory sources of power loss; (*b*) tests on the higher reduction-ratio gears extending up to loads and speeds in excess of normal, made to confirm the results of the first series and to determine the efficiency of the transmission under extreme conditions.

The method of test is described and the results are given graphically; and the authors draw the following conclusions: (*a*) an excess of or too viscous a lubricant causes

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excessive loss of power in the direct-drive position, (*b*) adequate lubrication of the indirect gears is given by sufficient oil just to cover the teeth of at least one of each pair of mating gears, and (*c*) an oil of moderately low viscosity gives satisfactory lubrication and minimizes churning loss.

ENGINES

The Balancing of Engines. By W. E. Dalby. Published by Longmans, Green & Co., New York City, and Edward Arnold & Co., London, fourth edition, 1929; 316 pp. and index, illustrated. Price $8.40. **[E-1]**

Professor Dalby set forth his method of solving balancing problems and of finding balance weights in the first edition of this volume, published in 1902. The method has since been widely accepted and used in textbooks.

According to the author, this method of reference plane and schedule enables a competent draftsman, using a drawing-board and slide rule, good draftsmanship and arithmetic, to find the balance weights for a complex system of masses about an engine crankshaft. The last chapter, The Balancing of Internal-Combustion Engines, will have the greatest interest for the automotive engineer.

Un Nouveau Compresseur Volumétrique à Grand Debit. By René Charles-Faroux. Published in *La Vie Automobile*, March 25, 1930, p. 117. **[E-1]**

A new rotating compressor, the P.Z., is described. Advantages claimed for it are volumetric efficiency, small weight and size, good mechanical efficiency, the discharge of gas without overheating it and without any trace of oil, silence of operation and small inertia of the moving parts. An example is given of such a compressor applied to a 2000-hp. marine Diesel engine, and the opinion is expressed that, with such a compressor as an auxiliary, engineers will be likely to view more favorably the possibilities of a two-stroke-cycle engine for automobile, aircraft and marine use.

Kohlenstaub-Dieselmaschinen. By F. Ernst Bielefeld. Published in *Automobiltechnische Zeitschrift*, April 30, p. 295, and May 20, 1930, p. 348. **[E-1]**

The possibilities of developing a Diesel engine capable of burning coal dust as fuel are discussed somewhat pessimistically. Technical and patent literature dealing with the design and operation of such an engine is reviewed, and the difficulties and dangers involved in preparing the right type of fuel are brought out. No important progress has been made in the development of such an engine, the author concludes, and to discuss its probable efficiency is useless, since no such engine is on the market and, even if it were, it is doubtful whether the price and the difficulty of procurement of the fuel would permit its use.

Progrès Réalisés Récemment dans la Construction d'un Moteur Diesel à Grande Vitesse. By Paul Dumanois. Published in *Le Génie Civil*, April 26, 1930, p. 408. **[E-1]**

Without detailed reference to specific commercial designs, the author views broadly the progress of the Diesel engine, and, on the basis of its fundamental advantages and restrictions, attempts to define its future possibilities. That it has not yet fulfilled the prophecy of its inventor, Dr. Diesel, that it would replace all other engines is not to be regarded too pessimistically; the practical development of the explosion engine consumed 30 years, and several years more may reasonably be required for the perfection of the Diesel engine.

Two paths of Diesel progress are distinguished: increasing the efficiency of the slow-speed engine, along which road important forward steps have been taken; and increasing the speed and hence the horsepower per unit weight, a

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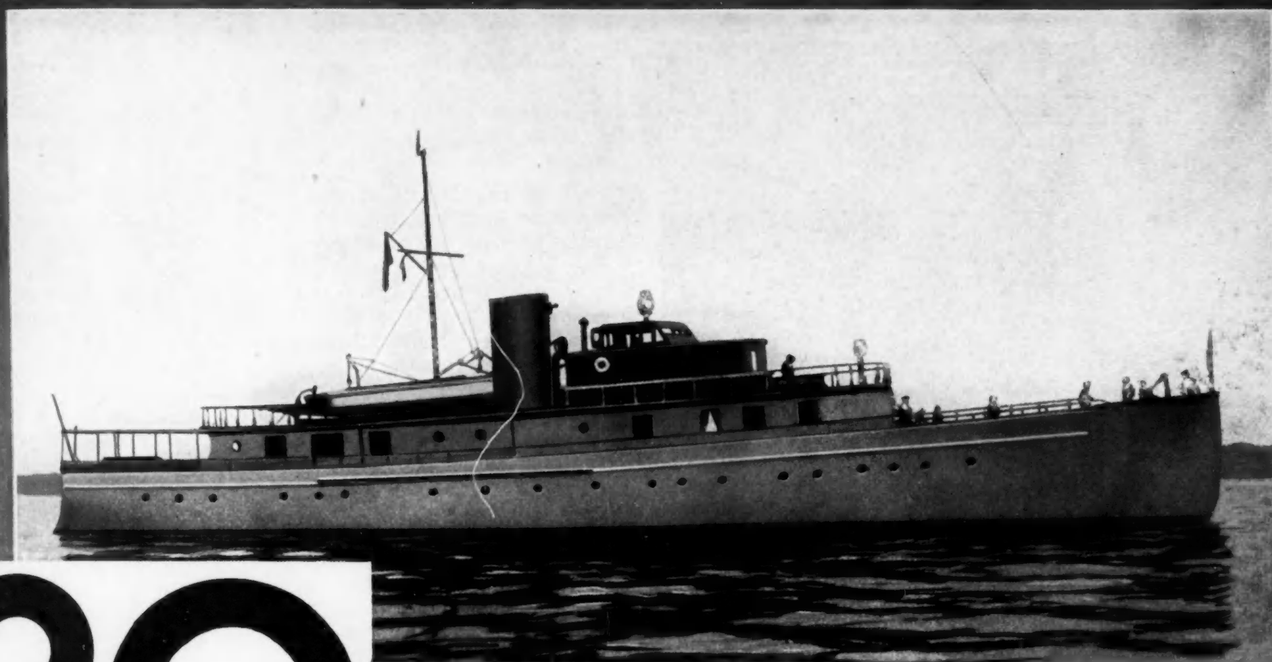

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direction in which advances have been retarded by thermodynamic, mechanical, physical, chemical and economic obstacles.

Of all the difficulties to be overcome, those of achieving complete combustion in the short time available in high-speed engines are said to be the most serious. That a solution has not yet been found is strongly indicated by the number and diversity of combustion-chamber designs with which experiments are still being made. The study of Diesel-engine combustion is complicated by the facts that high pressures and complex and varying fuels are involved. In addition to technical considerations, reference is made to the economic reactions on Diesel-engine progress.

The Lubrication of Engines. By O. Thornycroft and C. H. Barton. Published in *Aircraft Engineering*, February, 1930, p. 36. [E-4]

After several years of experimentation with specially designed apparatus and actual engines, the authors have reached certain conclusions which, because of the complexity of the subject and the fact that lubrication is not yet an exact science, they warn, should, in some cases, be taken merely as opinions.

The results of the experiments are discussed in considerable detail and the following conclusions with regard to the lubrication of aircraft engines are given in the continuation of the article, published in the May issue of *Aircraft Engineering:*

(1) The property of "oiliness" (possessed by fatty oils) is not of importance in oils intended for the lubrication of aircraft engines.

(2) The viscosity of a lubricant is important at two temperature-ranges, which are respectively related to the following two points: (*a*) supply of lubricant to the bearings at the lowest temperatures of the oil-circulating system, say +5 to —20 deg. cent., according to climate; (*b*) rate of oil consumption, the significant temperatures being between 80 and 110 deg. cent.

(3) The sludging tendency of an oil depends on its source and on the refining it has received. This property can be evaluated at present only by actual engine tests.

(4) Carbonization is due chiefly to the incomplete evaporation and combustion of lubricating oil in the cylinders. It seems probable that the carbonaceous matter that occurs in crankcases, and in sludge, is carried down from the cylinders.

(5) For normal fuel-air mixture-strengths the amount of carbon deposited in the cylinders is not appreciably affected by the fuel, but over-rich fuel-mixtures may increase the carbon deposits.

(6) The carbonizing tendency of mineral-oil distillates is less than that of bright stocks or fatty oils.

(7) Carbon deposits build up until an equilibrium condition is reached. At equilibrium the amount of deposit in a given engine depends upon the nature of the lubricant. The continued running of an engine is therefore profoundly affected by the carbonizing tendency of the lubricant.

(8) Even in a short running period, that is, 50 hr., not more than 20 per cent of the total quantity of lubricating oil consumed in a gasoline engine appears to leave carbon deposits.

(9) Cylinders of four-stroke air-cooled gasoline engines, working at very high temperatures, can be satisfactorily lubricated by mineral-oil distillates without the addition of bright stocks or fatty oils.

Although no entirely satisfactory laboratory test for comparing the carbonizing tendencies of lubricating oils is known, and apparently there is no test at all for sludging, the authors believe that, when more is known about the

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complex changes that occur to lubricants in use, the development of useful laboratory tests for these properties should be possible. It is essential, however, that any tests proposed should be worked out in conjunction with observations on the behavior of oils in engines.

HIGHWAYS

A Decade of Progress in Highway Research. By F. H. Eno. Engineering Experiment Station Circular No. 20. Published by the Ohio State University, Columbus, Ohio, March, 1930; 30 pp., illustrated. [F-1]

This circular has been prepared to provide, for busy engineers and others interested, a condensed account of some of the principal studies and improvements made in highway construction and maintenance in the last decade.

For convenience the researches reported have been grouped under three main headings: Study of Highway Subsoils, Important Discoveries in Road Construction, and Operation Factors. Descriptions of new machinery and equilibrium volatility from the A.S.T.M. distillation are patented materials and processes are omitted.

Fahrbahnreibung und Schlüpfrigkeit der Strassen im Kraftwagenverkehr. By Rudolf Schenck. Published by M. Krayn, Berlin, Germany. 62 pp.; 23 illustrations. [F-1]

Tests to determine the coefficient of friction between the tires of an automotive vehicle and road surfaces of various types and conditions are described. These tests complete an investigation during the first part of which, previously reported upon, a study was made of the action of pneumatic tires on dry, wet, snowy and icy streets, and of the action of solid tires on dry and wet streets. The later tests, described in the present report, were intended to throw light on the worst possible tractive conditions.

Road tests included those of solid-tired vehicles on snowy and icy streets. A 3-ton truck, the tires on which were worn until the tread was almost smooth, was used. Emphasis is placed on the fact that throughout the experiments the truck was operated under its own power, since values obtained from a vehicle being towed are said to be misleading when applied directly to conditions of practical usage. Values for the coefficient of friction obtained for about 10 different types of snowy or icy road surface were found not to differ widely, since they represent not the effects of the road surface itself, but of its covering of ice or snow. Results of previous tests are assembled with those of the present tests for purposes of comparison.

As a second section of the later work, laboratory tests were made to determine the relation of static to dynamic friction and to study the action of pneumatic and solid tires on extremely muddy streets, since it was not thought possible to make sufficiently accurate observations of such conditions in actual practice.

From the results obtained, conclusions are drawn as to the relative tractive merits of solid and pneumatic tires, allowable speeds and requisite stopping distances.

MATERIAL

Standard Methods of Testing Petroleum and Its Products. Published by the Institution of Petroleum Technologists, London, second edition, 1929; 137 pp. and index. Price 7s. 6d. [G-1]

This volume, which was first compiled in 1924 by the Standardization Committee of the Institution, serves in the British Empire as the official handbook for standard petroleum test-methods. Not only have methods of testing been considered, but also the standardization of apparatus. The committee has kept informed of American practice and in a number of instances has adopted the methods of test

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outlined by the American Society for Testing Materials and the United States Bureau of Standards. The new edition embodies the modifications and additions resulting from the experience gained during the last five years.

Motor-Fuel Volatility. I—Equilibrium Volatility. By George Granger Brown and Emory M. Skinner. Published in *Industrial and Engineering Chemistry*, March, 1930, p. 278. [G-1]

This is the revised form of the paper by the authors which was presented before the American Chemical Society in the spring of 1929.

Equilibrium volatility is defined as the per cent by weight vaporized under equilibrium conditions at specified temperature, pressure and air-fuel ratio. It has been found impossible, the authors contend, to determine accurately by any form of apparatus that has been described, the partial equilibrium volatility of motor fuels in the presence of air. Methods previously proposed for estimating the equilibrium volatility from the A.S.T.M. distillation are declared to be inaccurate. The authors show that this volatility can be computed accurately from the continuous equilibrium vaporization, or flash distillation, data by making proper allowance for the molecular weight of the vaporized part of the fuel.

Refrigerated-Wind-Tunnel Tests on Surface Coatings for Preventing Ice Formation. By Montgomery Knight and William C. Clay. Technical Note No. 339. Published by the National Advisory Committee for Aeronautics, City of Washington, May, 1930; 21 pp., 13 illustrations. [G-1]

This investigation was conducted in the refrigerated wind-tunnel at the Langley Memorial aeronautical laboratory to ascertain the effectiveness of various surface coatings as a means for preventing the formation of ice on aircraft in flight.

The substances used as coatings in these tests are divided into two groups: compounds soluble in water and those that are insoluble in water.

Certain soluble compounds apparently were found to be effective in preventing the formation of ice on an airfoil model, while all the insoluble compounds tested were found to be ineffective.

The Creep of Steel at High Temperatures. By F. H. Norton. Published by the McGraw-Hill Book Co., Inc., New York City and London, 1929; 88 pp. and index, illustrated. Price, $3. [G-1]

The investigation of the creep resistance of steels herein reported was undertaken at the request of the Babcock & Wilcox Co., and was conducted in the department of physics at the Massachusetts Institute of Technology.

The paper provides the engineer with data on the safe stresses for various steels, especially at high temperatures. The methods and results of other experimenters are briefly reviewed, the Babcock & Wilcox creep-testing apparatus is described, the creep results for 17 types of steel at temperatures above 1000 deg. fahr. are given, and the significance of the results is discussed.

The author points out that much is still to be done on the development of research apparatus for accurately determining the creep resistance of steel.

Bearing Metals and Bearings. By W. M. Corse. American Chemical Society Monograph Series. Published by the Chemical Catalog Co., Inc., New York City, 1930; 374 pp. and index. Price, $7. [G-1]

A survey of the literature on bearing metals and bearings showed that a great many valuable articles had been published in various foreign and domestic periodicals and in the transactions of technical societies. This material was

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so widely scattered, however, as to be almost useless. At the suggestion of the committee in charge of the Monograph Series of the American Chemical Society, the author prepared this volume, which includes an extensive bibliography on the subject, abstracts of selected papers, and tables showing the properties of bearing metals. The chapters preceding the bibliography give briefly the fundamental principles involved in the selection of bearings and bearing metals.

This book is a valuable contribution to its field and its use is facilitated by both an author and a subject index.

Materials of Engineering Construction. By Francis W. Roys. Published by The Ronald Press Co., New York City, 1930; 306 pp. and index, illustrated. Price, $4. [G-3]

This book has been planned and written as a text for the student of engineering, to enable him to obtain a close acquaintance with the characteristics and properties of the more common and most widely used materials of engineering. The author declares that no attempt has been made to produce a manual of engineering materials, and for that reason the treatment is rather different from that of most college texts on the subject. Explanations and descriptions are brief, photographs have been used freely and a wide scope in reference-book material has been consulted.

The chapters that will have the most interest for the automotive engineer are: Ferrous Metals, Non-Ferrous Metals and Alloys, Corrosion of Metals, Temperature Effects on Metals, Failure of Material under Repeated Stress, and Varnishes and Paints.

MISCELLANEOUS

Bilan Technique. By A. Caputo. Published in *Omnia*, April 1930, p. 732. **[H-1]**

Automobiles, as a means of transportation, have penetrated into fields formerly thought closed to them, and, as instruments of service aside from transportation, have taken on the performance of functions formerly considered foreign to them. This the author brings out as one of the significant developments in recent automotive history, and instances as specific examples trans-Saharan automobile travel, industrial and farm tractors, and the increasing and specialized use of motor-trucks.

The term touring-car, now a misnomer, should be replaced by business or service car, in the opinion of the author. He points out as the most fruitful field for future research, suspensions, the ability to hold the road, and bodies. Two specific design features emphasized as necessary improvements are the abolition of the front axle in favor of independent wheel suspension and the adoption of the rigid chasis. Silent gears and economical small cars, perhaps of the three-wheel type, are also objectives meriting serious consideration.

Le Concours International d'Appareils Chasse-Neige du Touring Club de France. By Jacques Thomas. Published in *Le Génie Civil*, March 22, 1930, p. 277. **[H-1]**

Snow removal was given its primary impetus in France by the Touring Club of France, which directed its first efforts along these lines toward keeping open the Alpine routes. As a means of accelerating interest in the problem of keeping the roads free for winter transportation, this organization recently held an international competition for snow-removal apparatus. This type of highway maintenance does not always involve the total removal of snow, as in many sections a sufficient layer must be left to make possible sleigh transportation or the dragging of timber.

Four types of apparatus are referred to: the straight scraper or shovel; the wedge-shaped; the rotating or turbine, and the continuous-chain type.

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In the contest the apparatus was grouped into two classes; the heavy and the light duty. A Juste continuous-chain type of remover in combination with a Cletrac tractor won the prize in the first class, against four other entries; while in the second class two wedge-shaped scrapers, the Latil and the Viking, were judged equally superior to their five competitors and divided the award between them.

The design and performance of the entries are detailed and the conclusion is drawn that for fresh snowfalls wedge-shaped scrapers propelled by suitable power, are sufficient, provided the work of removal is started before too much snow has fallen, but that for hardpacked or frozen deposits mechanical means of disintegration and digging are necessary.

The Commercial Standards Service and Its Value to Business. Published by the Bureau of Standards, United States Department of Commerce, Government Printing Office, City of Washington, 1930; 34 pp., illustrated. **[H-3]**

This leaflet sets forth in an interesting and convincing way the value of standardization and traces the origin, evolution and effects of commercial standards.

Foundry Practice. By R. H. Palmer. Published by John Wiley & Sons, Inc., New York City and London, fourth edition, 1929; 438 pp. and index, illustrated. Price $3.50. **[H-5]**

This volume, first presented in 1911, follows the scheme of instruction used by the author in his work as an instructor in foundry practice at the Worcester Polytechnic Institute. It begins with the simplest type of mold and leads the student and apprentice gradually through the more difficult lines of work in green and dry sand and loam. Typical examples are used to illustrate the different practices, and such other subjects of foundry practice as cupola practice, mixing and melting, cleaning and repair of castings are also included.

The author states as his purpose, "the making of a text-book for the student, apprentice and molder and a useful work for the general foundryman."

Standard Costs. By G. Charter Harrison. Published by The Ronald Press Co., New York City, 1930; 292 pp. and index. Price, $5. **[H-5]**

Mr. Harrison, a member of the firm of Stevenson, Harrison & Jordan, is one of the foremost exponents of modern management methods as applied to cost accounting. In this book he has made available the exact details of the methods he has worked out. He gives practical procedure for setting standard costs in factory, shop and sales office; designing, installing and operating standard cost-systems; checking actual against standard costs; getting at causes of cost and profit variations; and reporting results of the application of standard costs. His methods cover the entire problem, from compiling the original data through determining budgets and measuring the results of operations.

The book has an extensive index.

Materials-Handling Equipment. By Edward J. Tournier. Published by the McGraw-Hill Book Co., New York City and London, 1929; 363 pp. and index, illustrated. Price. $4. **[H-5]**

The author states his purpose in writing this book to be to set forth the results, in service, of those mechanical handling devices which are most frequently used, to show how these forms are adapted to different uses, to indicate the methods by which a proper selection can be effected, and to serve as a guide to the most economical methods in purchasing the machinery selected.

Rapid changes often make necessary the fitting of machinery to existing buildings, thus demanding compromises

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on the part of the conveyor engineer. These compromises are discussed by Mr. Tournier and certain formulas are given which may be used to determine, in advance, the possible gains from the installation of materials-handling equipment.

MOTOR-TRUCK

The Trends in Truck Design. By James W. Cottrell. Published in *The Commercial Car Journal and Operation and Maintenance*, February, 1930, p. 22. [K-1]

Truck manufacturers incorporated in their newer offerings in 1929 a flexibility of design which enables them to meet widely varying requirements of truck users. New models produced show not only a wide diversity of construction but, in many cases, options on major units such as engines, transmissions and rear axles. The number of manufacturers offering these options has increased, and among those now in this category are several that are on a large-production basis. An analysis of specifications shows two ways of incorporating this flexibility in design models. The first is by offering options on major units in a given model, and the second is by making a larger number of models, each incorporating a different unit or units.

The author points out that six-cylinder engines, transmissions with four or more speeds, full-floating axles and four-wheel brakes swept still further ahead of all rivals. Six-wheelers are much in evidence among trucks of more than 5-ton capacity. Balloon tires practically superseded pneumatics in the ½ and ¾-ton class and are available on trucks up to and including 3½-ton capacity. Smart appearance and streamlining of hood, cowl and body are other features noted by the author.

The Scammell 100-Ton Transporter. Published in *The Automobile Engineer*, March, 1930, p. 87. [K-1]

Although the laws of Great Britain prohibit the employment of vehicles capable of carrying 100 tons of ordinary merchandise, the use of such machines is sanctioned under the Locomotives Act for the transportation of machinery and similar bulk loads that cannot be subdivided. Steam turbines, alternators and transformers, boilers, locomotives, special chemical plants, cranes, and forgings and castings for marine engines, have reached such dimensions that they cannot be taken by rail on account of the limitations of the English loading gage. The Scammell firm undertook to design a vehicle forming a complete unit capable of transporting 100 tons without assistance from tractors.

The new machine embodies many of the salient features of the existing Scammell articulated vehicles. To meet the emergency of having the driving wheels sink into soft ground, ingenious provision has been made in the new giant Scammell machine for lifting the driving wheels of the motive unit clear of the ground in a few minutes, so that timbers or steel plates can be placed under them, enabling the vehicle to proceed again.

To prevent "cutting in" when turning sharp corners as well as to facilitate backing with this 40-ft. wheelbase vehicle, steering-gear has been provided for the rear carrier wheels. Hydraulic elevating gear is provided by means of which the center of the carrier can be raised 9 in. above its normal running position to provide additional road clearance. On the other hand, the center of the carrier can be depressed 9 in. below the normal, when passing under a bridge in which the profile of the road is concave and the normal clearance under the carrier frame is more than adequate. To avoid damage to roads, the whole vehicle must run on rubber tires. It has 14 wheels, 12 of which are mounted in pairs on relatively short axles, each of which can oscillate to conform to the camber of the road, while the construction of the motive unit and carrier assures even distribution of the load between the individual axles.

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Power is furnished by the same engine as is fitted to the Scammell eight-wheel carrier. Of the overhead-valve type, it has a bore and stroke of 5 and 5½ in. respectively, giving a cubic capacity for the four cylinders of 7094 cc. (432.73 cu. in.). The output of the engine is approximately 80 hp. on the brake.

Full details and drawings are given of this 100-ton transporter, which is said to be the largest mechanically propelled road vehicle in the world.

PASSENGER CAR

The Automobile Engineer Reference Book. Compiled by the editorial staff of *The Automobile Engineer.* Published by Iliffe & Sons, Ltd., London, second edition, 1929; 179 pp. and index. Price, 7s. 6d. [L-3]

This widely known and recognized technical reference book has been revised throughout. It constitutes a valuable record of formulas and data and contains numerous conversion tables, the last named having been added to and generally rearranged to conform with modern requirements.

Articles also appear dealing with Supercharging, Piston Clearances, Modulus of Flywheels, Gearbox Calculations, Back Axles, Front Axles, Steering-Gear, Brakes and Laminated Springs. The French-English dictionary included in the volume is a notable feature.

TRACTOR

Nebraska Tractor Tests, 1920-1929. Bulletin 242. Published by the University of Nebraska, College of Agriculture Experiment Station, Lincoln, Neb., March, 1930; 27 pp. [M-1]

With the close of the testing season of 1929 came the end of the tenth year of tractor testing at the University of Nebraska. A total of 166 tests have been conducted, and this bulletin summarizes the results of 61 of these and includes data on all tractors reported by their manufacturers as on the market Jan. 1, 1930.

All tractors tested are certified by the manufacturer as being stock-model machines, conforming to specifications filed with the application for test. No special or high-test fuels are used. All results shown in reports are those actually attained in tests and are without corrections or allowances for friction, temperature, altitude and so forth.

Complete reports for each tractor are available, and this bulletin is compiled from these reports. A tabular summary is given on a large folded sheet on the inside of the front cover.

An Act of Faith in Modern Equipment. The Allis-Chalmers Model-U Tractor Plant. By Otto H. Falk. Published in the *American Machinist,* March 13, 1930, p. 435. [M-5]

This statement by the president of the Allis-Chalmers Mfg. Co. introduces a series of authoritative, signed articles covering in detail the conception, layout, building and tooling of the new Allis-Chalmers Model-U tractor plant.

For the first time in 53 years, the editor of *American Machinist* explains, that publication has dedicated an entire issue to the work of one industrial plant. That the Allis-Chalmers project was planned and carried out in the face of pessimistic rumors of depression, that the plant is equipped throughout with brand new tools, and that it is already operating profitably and to capacity, are the reasons given for the radical departure from editorial custom. The articles included are as follows:

All-Modern Equipment Produces Allis-Chalmers Tractor, by William Watson; Completely Mechanized Foundry for Tractor Castings, by E. A. Harrison; Case-Hardening Practice for Tractor Gears, by J. Fletcher Harper; Heavy Castings and Special Machines, by H. W. Liebert; and Special-Purpose Equipment for Accurate Tractor Parts, by Frank J. Oliver, Jr.

Personal Notes of the Members

S.A.E. Members Elected by N.A.C.C.

Alvan Macauley, president of the Packard Motor Car Co., of Detroit, was reelected president of the National Automobile Chamber of Commerce at the recent annual meeting of the Chamber in New York City. New directors elected included, besides Mr. Macauley, A. J. Brosseau, A. R. Erskine, William E. Metzger and E. L. Cord. Mr. Erskine was elected vice-president to represent the passenger-car division; Mr. Brosseau, vice-president to represent the commercial car division; and H. H. Rice, treasurer. John N. Willys resigned the chairmanship of the export committee after his appointment as United States Ambassador to Poland.

Harry Abrams has recently accepted a position with the Amtorg Trading Corp., of New York City. He was previously a machine and tool designer with the Colonial Radio Corp. of Long Island City, N. Y.

Roy C. Allan, until lately manager of the New York City branch of the Bendix-Stromberg Carburetor Co., was recently appointed vice-president and general manager of the Bendix Service Corp., with headquarters at South Bend, Ind.

Walter G. Barcus has recently been appointed a research engineer with the National Advisory Committee for Aeronautics at Langley Field, Hampton, Va. He was previously a student aviator at the United States Navy Naval Air Station, at Pensacola, Fla.

Roland G. Bernd, designing engineer for aircraft, has severed his connection with the Szekely Aircraft & Engine Co. of Holland, Mich., to accept a position with the Leonard Motorless Aircraft Co., Inc., of Grand Rapids, Mich.

Carl E. Blass, a former student at the Carnegie Institute of Technology, has become a member of the production department of the Hookless Fastener Co., of Meadville, Pa.

Vance Breese is now assisting with designing, sales and test work with the Detroit Aircraft Co., of Detroit. Until lately he was president of the Breese Aircraft Corp., of Portland, Ore.

Roy O. Brooks, formerly manager of the northern California branches of the Standard Safety Corp., of Los Angeles, recently relinquished his post to become a traveling sales representative for the Woodlite Co., Ltd., of Hollydale, Calif.

Gerald E. Brower was recently transferred from his post at Wright Field, Dayton, Ohio, where he was chief of the airplane branch of the United States Army, and is now commanding officer, first pursuit group, Air Corps, United States Army.

W. H. Bushkin has been transferred from his post as sales manager of the accessory division of the Cadillac Motor Car Co., of Detroit, and has been appointed the company's parts and service manager for the Pacific region. His headquarters will be in San Francisco.

J. Lansing Callan has been elected president of the newly organized J. Lansing Callan Co., of Hammondsport, N. Y. He was formerly president of Airships, Inc., also of Hammondsport.

Petrus A. Carlson is now a designing engineer with the Sikorsky Aviation Corp., of Stratford, Conn. His previous connection was as chief engineer of the Commercial Aircraft Co. of America, at Bridgeport, Conn.

John Chucan has severed his connection as chief engineer with the Mercury Mfg. Co., of Chicago, and is traveling in Europe.

John S. Cole, who is serving the Texas Co. in the capacity of automotive engineer, has been transferred from Roanoke, Va., to the company's offices at Raleigh, N. C.

P. A. Collins, for the last year and a half sales engineer with the Bendix Brake Co., of South Bend, Ind., was re-

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Personal Notes of the Members

Continued

cently appointed to the position of sales manager of the Muncie Products Division of the General Motors Corp., at Muncie, Ind.

George R. Davenport, formerly on the engineering staff of the Studebaker Corp., and more recently with the Graham-Paige Motors Corp., has taken a similar position with the Hupp Motor Car Co. of Detroit.

C. H. Dengler, until lately chief engineer of the New Way Motor Co., of Lansing, Mich., is now a designing engineer with the Westinghouse Electric & Mfg. Co., of East Pittsburgh, Pa.

R. L. DeSpain, former district sales representative for the International Harvester Co. at Denver, Col., has relinquished that post to become automotive district superintendent for the Shell Petroleum Corp., with headquarters in the Shell Building in St. Louis.

Ernest Dickey, until recently chief engineer for the Delco Light Co., of Dayton, Ohio, is now research engineer with the North East Appliance Corp., of Rochester, N. Y.

Charles L. Drake, who has been serving the Yale & Towne Mfg. Co. in Detroit as assistant manager in the automotive division, is now engaged in the sales department, automotive division, of the Fafnir Bearing Co., of New Britain, Conn., as sales engineer.

H. F. Foster has been advanced from the post of district engineer with the Consumers Power Co., of Grand Rapids, Mich., to that of distribution safety engineer at that company's Jackson, Mich., plant.

William Gauvain, a former New York University student, is now employed by the Hall-Aluminum Aircraft Co., of Buffalo, as a junior engineer.

William S. Hadaway recently relinquished his post with the Edison Lamp Works, of Harrison, N. J., to occupy a similar post with the Westinghouse Lamp Co., of Bloomfield, N. J.

M. Hamon has severed his connection with the Curtiss Flying Service, Inc., of Stratford, Conn., manager of the Bridgeport Airport, and is now serving as automotive engineer with the Shell Eastern Petroleum Products Corp., of New York City.

H. Brewster Hobson recently became president of Hobson-Buell, Inc., of New York City. He was formerly an engineer with the Venezuelan Petroleum Co., of the same city.

J. B. Jackson has been made general manager of the Jaxon Steel Products Division, General Motors Corp., at Jackson, Mich. Until recently he was director of the general service staff and business director of the research laboratories for the General Motors Corp., of Detroit.

S. Johnson, Jr., has been appointed chief engineer of the newly-formed Bendix-Westinghouse Automotive Air Brake Co., at Pittsburgh. He was formerly identified with the Chicago office of the automotive brake division of the Westinghouse Air Brake Co.

William H. Kelley, who is serving the John H. McGowan Co., of Cincinnati, has been advanced from assistant factory superintendent to general superintendent for that company.

J. M. Klements is now serving the Pierce-Arrow Motor Car Co., of Buffalo, as full-sized-body-layout draftsman. His former connection was with the Baker-Raulang Co., of Cleveland, as body draftsman.

F. K. Knohl has been appointed a research engineer with the Illinois Tool Works, of Chicago. Prior to accepting this position he was a truck designer for the Fargo Motors Division of the Chrysler Motor Co., at Highland Park, Mich.

G. C. R. Kuiper, who until lately was chassis experimental engineer for the Stutz Motor Car Co., of Indianapolis, is now assistant to the chief engineer of the Midland Steel Products Co., of Cleveland.

Abbot A. Lane, former mechanical engineer with Stevens & Wood, of New York City, is now associated with the Allied Engineers, Inc., of the same city.

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Personal Notes of the Members

Concluded

Henry G. McComb recently relinquished his post as development engineer with Servel, Inc., of Evansville, Ind., and is now occupying a similar post with the Majestic Household Utilities Corp., of Chicago.

W. A. McCutcheon, who was superintendent of the Motor Transit Management Co., of Chicago, is now president of the White Swan Lines, Inc., operating motorcoaches in Columbus, Ohio.

J. B. Murray, a former motor-oil demonstrator for the Texas Co., in Norfolk, Va., is now service-station supervisor for that company and is stationed at Asheville, N. C.

Alfred L. Nichols recently gave up his position as automotive engineer with the Vacuum Oil Co., of Melbourne, Australia, and is now manager for the firm of Ramsay & Treganowan, Ltd., also of Melbourne.

Yoshio Ogawa is now discharging the duties of manager of the International Engineering Exchange, of Los Angeles. Prior to forming this connection he was service manager for the General Motors of Japan, Ltd., at Kobe, Japan.

Clyde A. Ohl, formerly a representative of the Westinghouse Air Brake Co. in Chicago, is now district sales manager for the new Bendix-Westinghouse Automotive Air Brake Co., at Pittsburgh.

A. G. Plimmer has assumed the duties of foreman in charge of the experimental department of the Cincinnati Grinders Co., Inc., of Cincinnati. He was previously a machine designer with the National Carbon Co., of Fremont, Ohio.

G. A. Schrieber, consulting engineer, who has been visiting in this Country, recently returned to Germany and will have his headquarters in Berlin.

W. W. Slaght is now chief engineer for the Cleveland Steel Products Co., of Cleveland. He was until recently a chassis experimental engineer for the Pierce-Arrow Motor Car Co., of Buffalo.

Ray W. Springer, formerly vice-president and general manager of the Superior Felt Products Co., Inc., of Flint, Mich., is now president and general manager of the Feltex Mfg. Co., of Detroit.

D. T. Stanton, until lately assistant sales manager of the Chrysler Export Corp., of Detroit, is now director of sales for the Dodge Brothers Corp., also of Detroit.

Robert F. Steeneck, who for the last two years has been the western representative of the Fafnir Bearing Co., is now assistant manager of distributors sales at the company's New Britain, Conn., factory.

Hans. A. von Storp, formerly a designer with the Hupp Motor Car Corp., of Detroit, is now metallurgical contact man for Adam Opel A. G. Russelsheim, Main, Germany.

T. I. Wagner, a former student of New York University, has assumed the duties of manager of the repair department of the Hamilton Standard Propeller Corp., of Pittsburgh.

Charles F. Wasserfallen, for years works manager and chief engineer of Detroit Carrier & Mfg. Co. and later vice-president in charge of manufacturing of the Oakes Division, Houdaille-Hershey Corp., has severed these connections and has announced no future plans.

Leo J. Werner, who was production designer for the Brandes Products Corp., of Newark, N. J., is now an engineer with the C. M. Grey Mfg. Co., of East Orange, N. J.

At a recent meeting of Wheels, Inc., of New York City, **Thomas J. Wetzel** was elected chairman of the board, **John F. Creamer** became president and treasurer, and **James Mattern** was elected a vice-president.

S. "Dick" Woods, formerly chief engineer of the Craveroiler Co. of America, at Philadelphia, is now automotive engineer for the Continental Oil Co., of Ponca City, Okla. Mr. Woods is a well-known racing man and contest-car engineer.